Introduction to Computer Networks

CS640

L2 Switching

https://pages.cs.wisc.edu/~mgliu/CS640/S25/index.html

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Outline

- Last
  - Framing and Error Handling
- Today
  - L2 Switching
- Announcements
  - Lab1 due on Feb 11th 11:59pm
  - Quiz1 on Feb 13th in-class

Ethernet

- The most popular wired computer network technology
  - Co-invented by Robert Metcalfe (Turing Award 2023)
  - First developed at Xerox PARC for Alto computers to communicate
  - IEEE 802.3 standards
  - Widely used in local area network (LAN) and wide area network (WAN)

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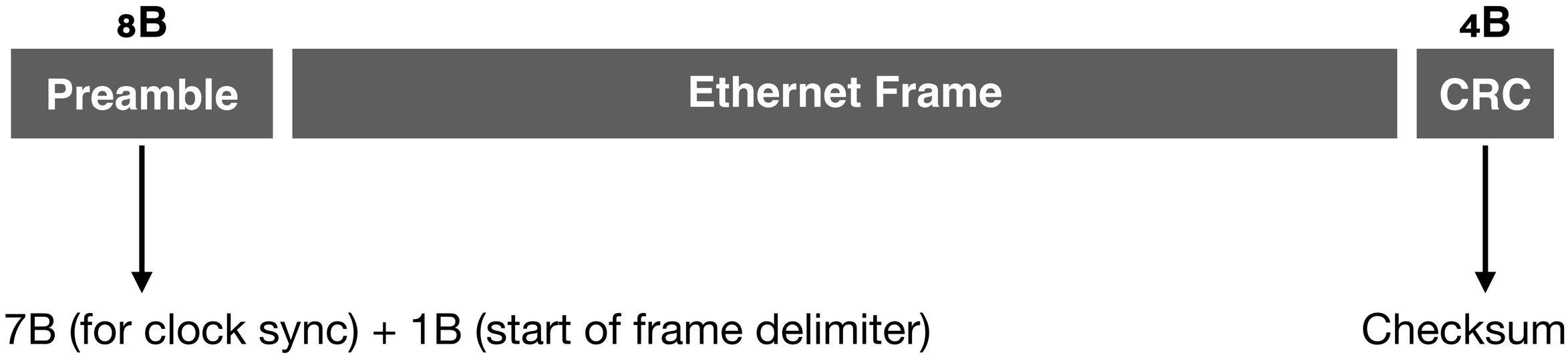
We will discuss L2 switching based on Ethernet.

Ethernet Framing

- Ethernet uses the bit stuffing technique
- Ethernet uses the CRC checksum for error handling



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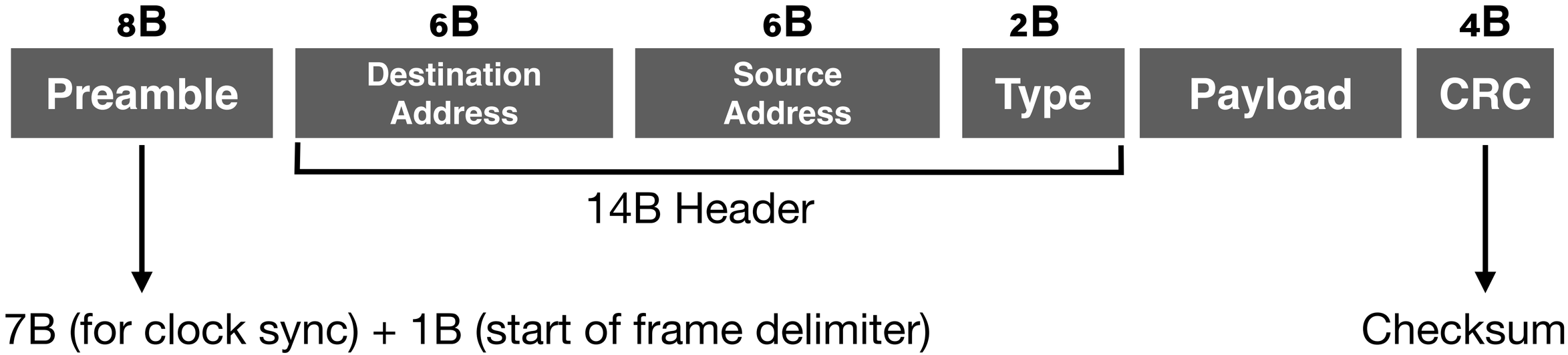
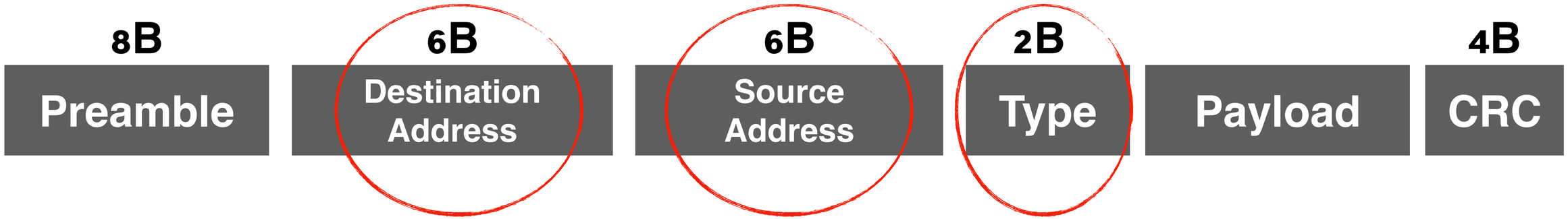




What is an address?
What is a type?

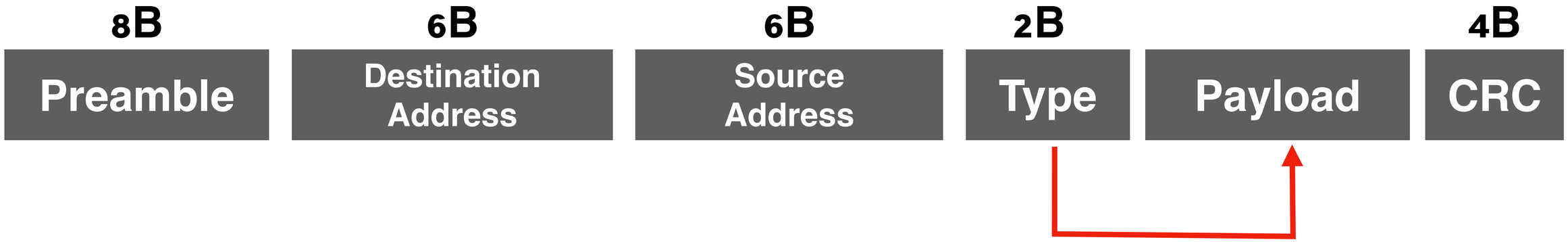
MAC Address

- MAC = Media Access Control Address
  - A unique identifier for a switch (and NIC) port
  - Originally from the Xerox System Ethernet Addressing scheme
  - 48-bit, e.g., bc:97:e1:13:82:d4

- Assigned by the hardware vendor
  - The first three bytes identify the organization
  - Also known as the organizational unique identifier (OUI)
  - https://www.wireshark.org/tools/oui-lookup.html

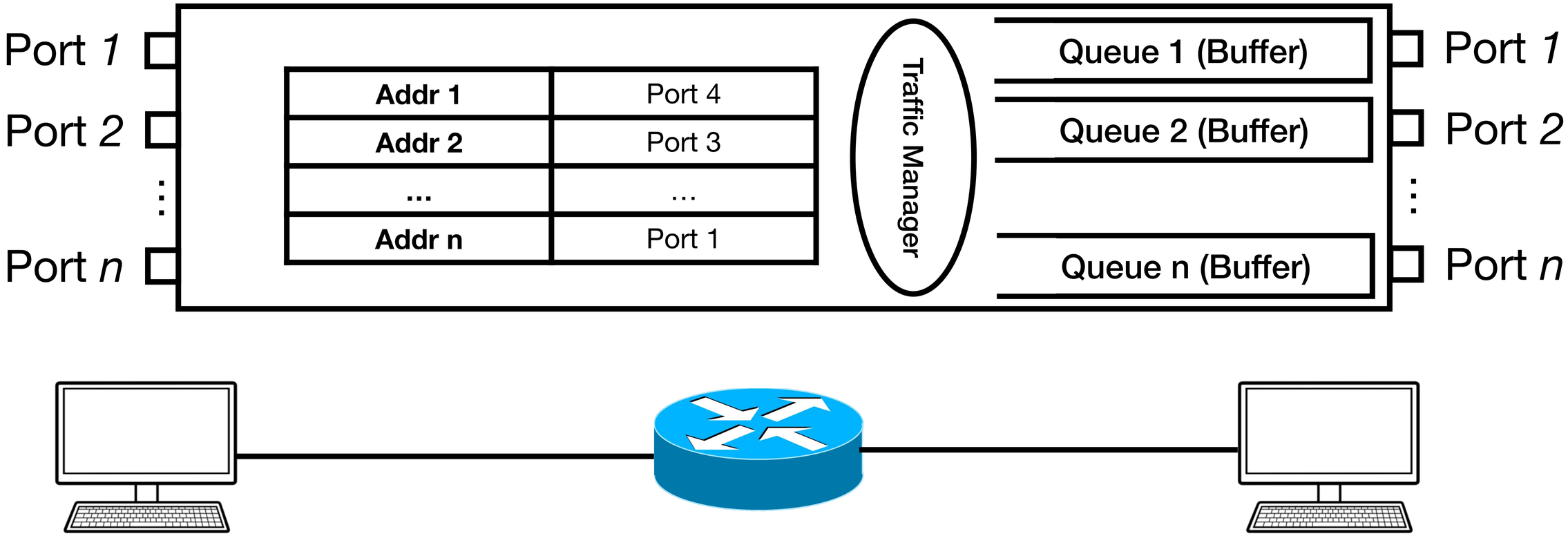
Ethernet Frame Type

- Indicate which protocol encapsulates the payload
  - 0x0800 —> IPv4 (Internet Protocol Version 4)
  - 0x0806 —> ARP (Address Resolution Protocol)
  - 0x08DD —> IPv6 (Internet Protocol Version 6)



After identifying an Ethernet frame, how does the switch/router forward it?

Recap: Packet Switching



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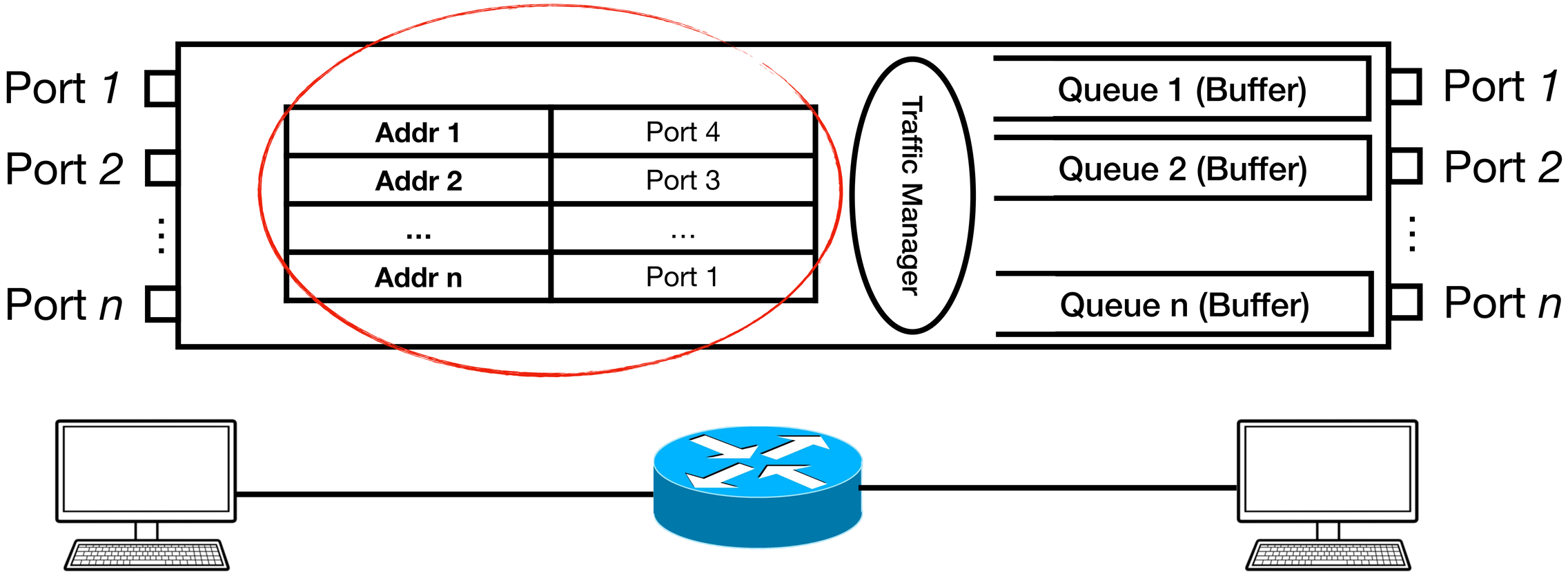

Forwarding Table

- Each switch/router maintains a forwarding table:
  - <MAC address, port, age>
  - Mac address: the destination MAC address
  - Port: the forwarding port number of the switch
  - Age: the valid period of the entry

MAC address	Port	Age (s)
11:22:33:44:55:66	1	2
77:88:99:aa:bb:cc	3	4
dd:ee:ff:11:22:33	2	6

How does the frame forwarding work?

- For an incoming frame,
  - The switch looks up the forwarding table and performs an exact match
  - If there is a hit, send the frame to the matched port
  - If there is a miss, do broadcast, i.e., **send the frame to all ports except the incoming port**

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Ethernet Frame

77:88:99:aa:bb:cc	**11:22:33:44:55:66**	**0x08 00**	**Payload**

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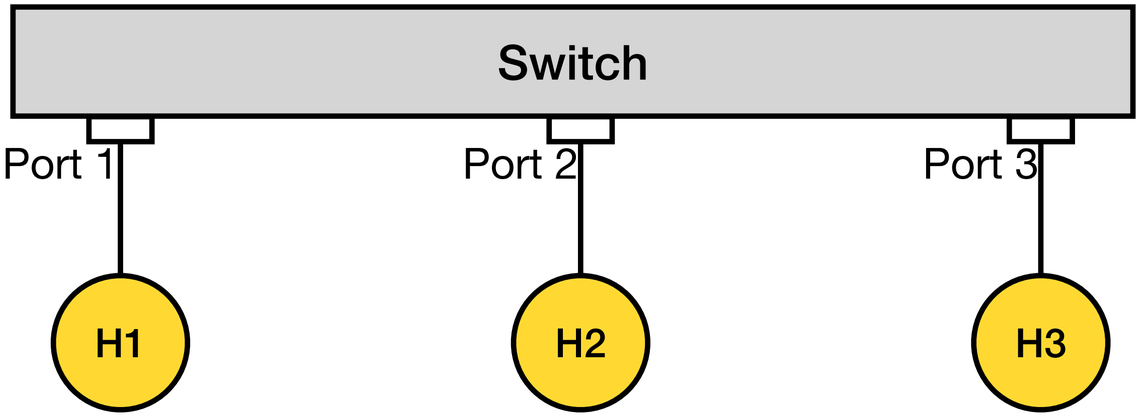
An Example



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How is the forwarding table filled up?

MAC Learning

- An automatic MAC (forwarding) table filling technique
  - Keep track of the source address of a frame and the arriving port

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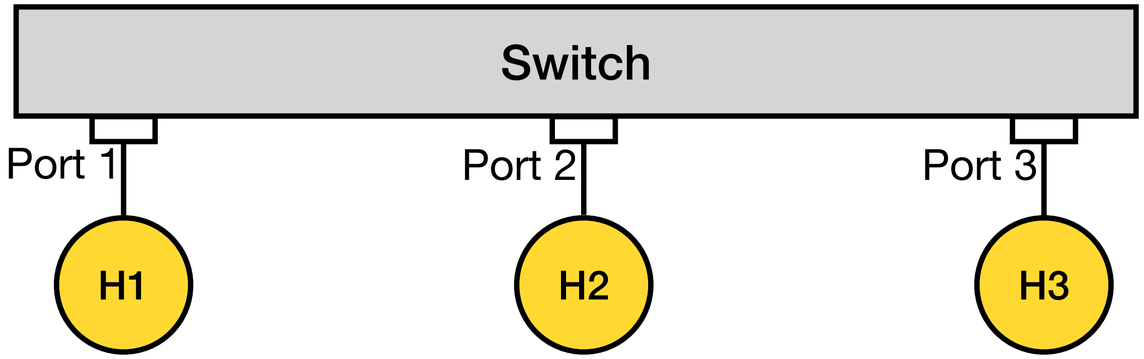

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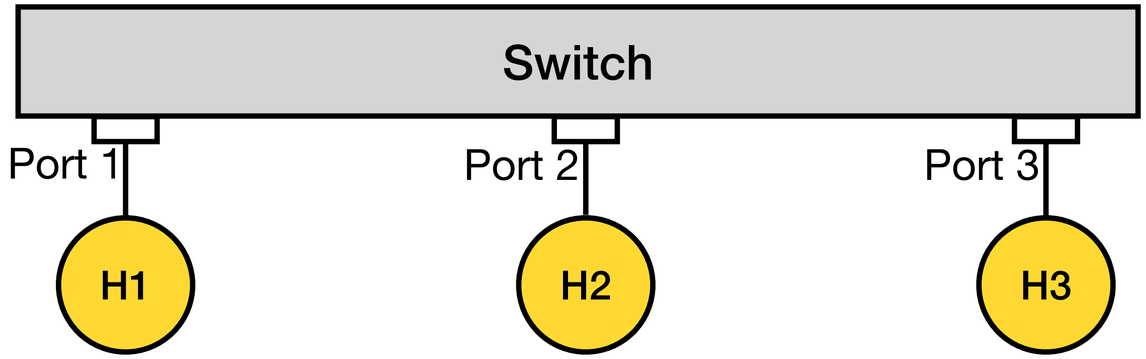

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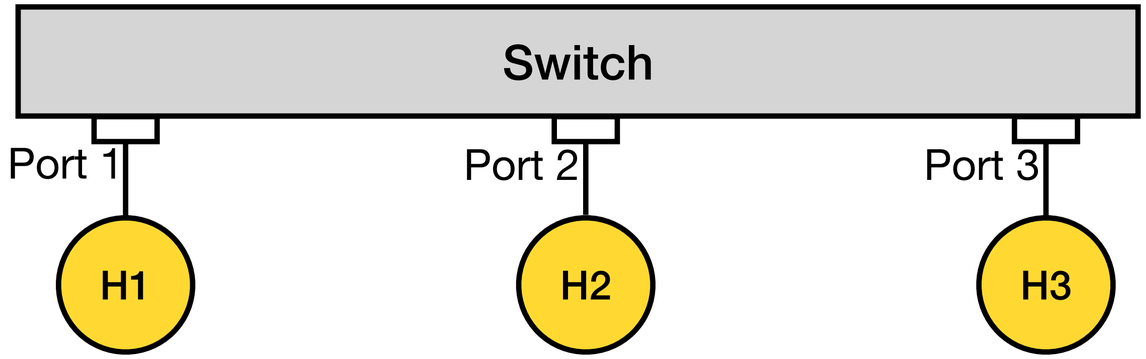

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Host1 -> Host3

- The frame comes to port 1 and is broadcast
- The default aging time is 10s

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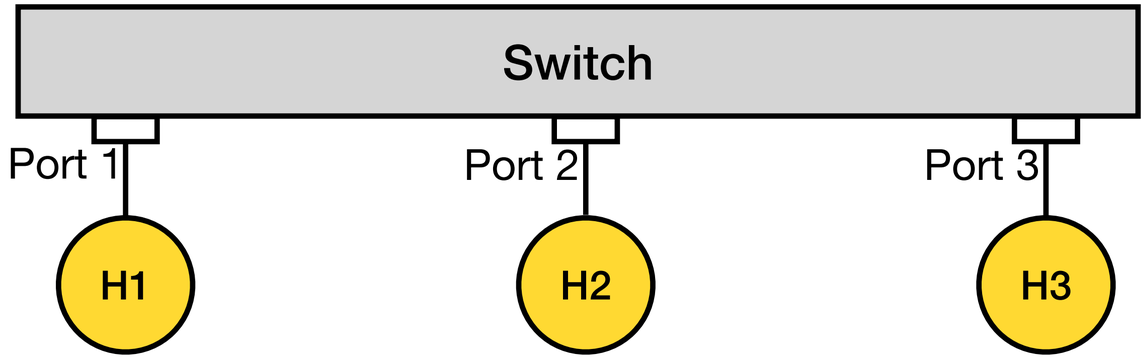

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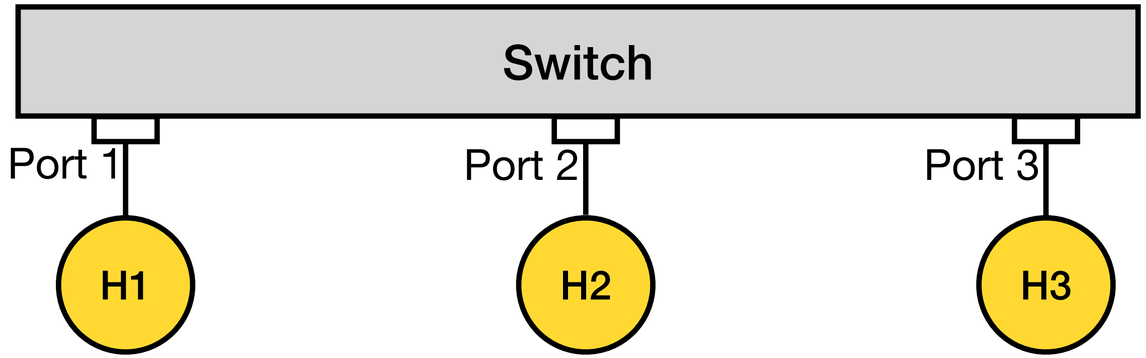

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Host3 -> Host2

- The frame comes to port 3 and is broadcast
- The default aging time is 10s

MAC address	Port	Age (s)
11:22:33:44:55:66	1	8
77:88:99:aa:bb:cc	3	10

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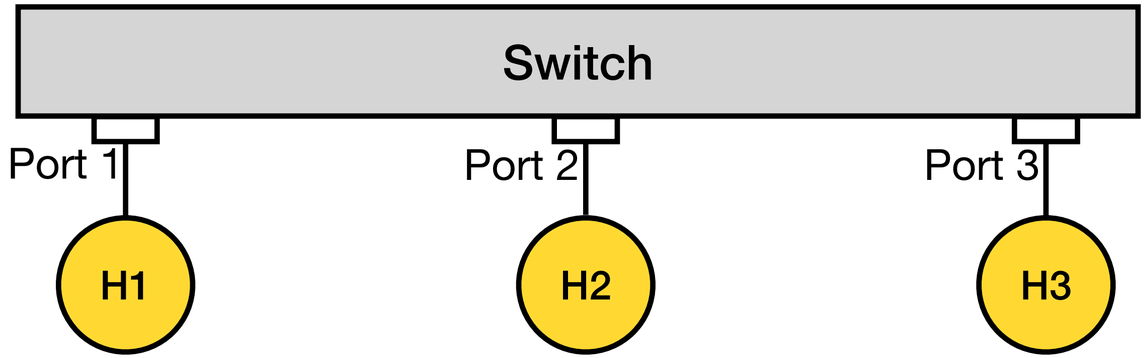

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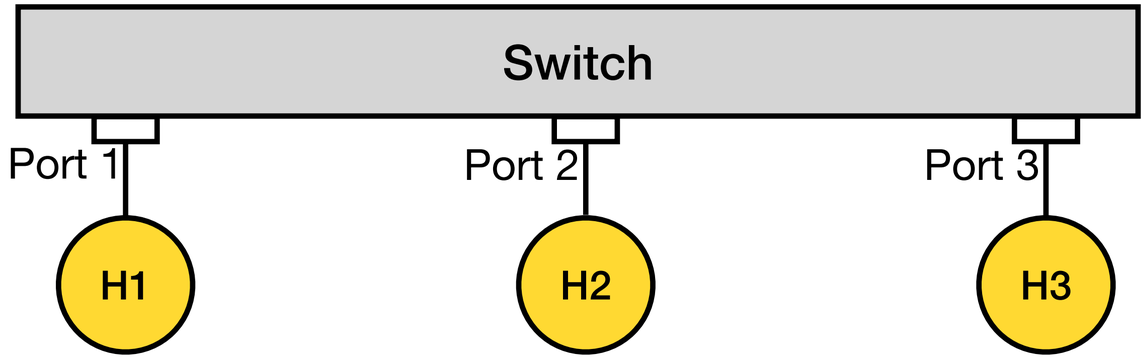

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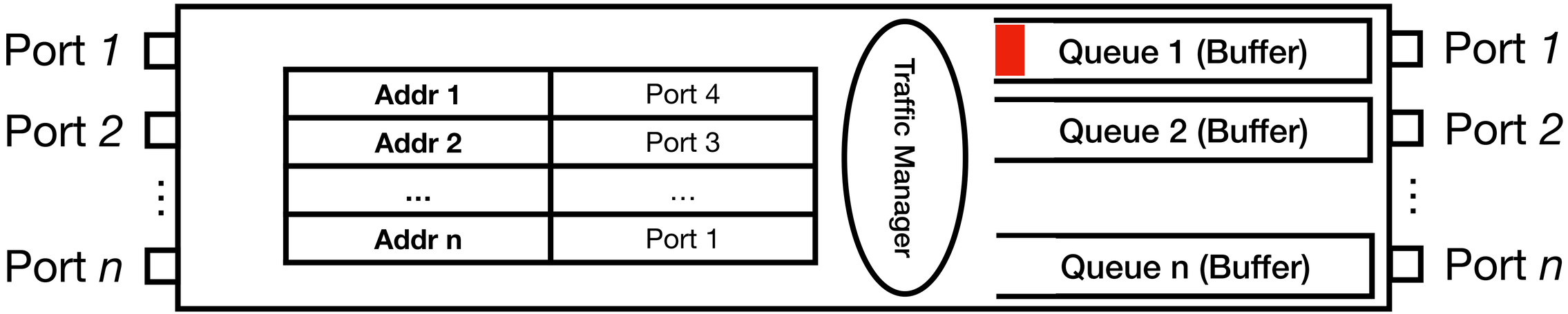
Recap: Store-and-Forward Transmission

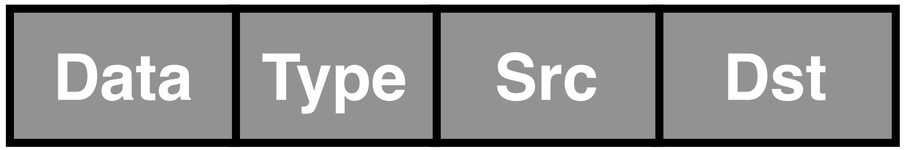
- The hardware can only forward after receiving the entire packet
  - Packets need to be buffered!

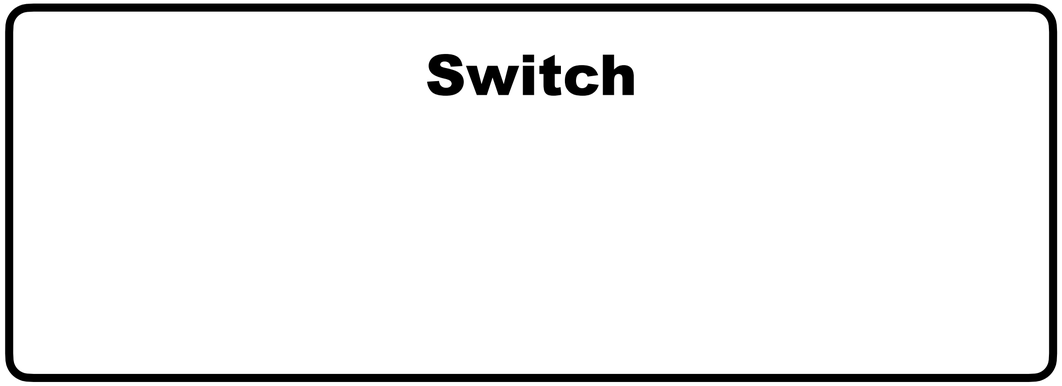
- Suppose a packet has *L* bits, and a switch transmits at *R* bits/sec
  - The switch takes *L/R* time to transmit the packet at the outbound port



Store-and-Forward under Ethernet

- The switch should wait to forward the frame until receiving an entire frame





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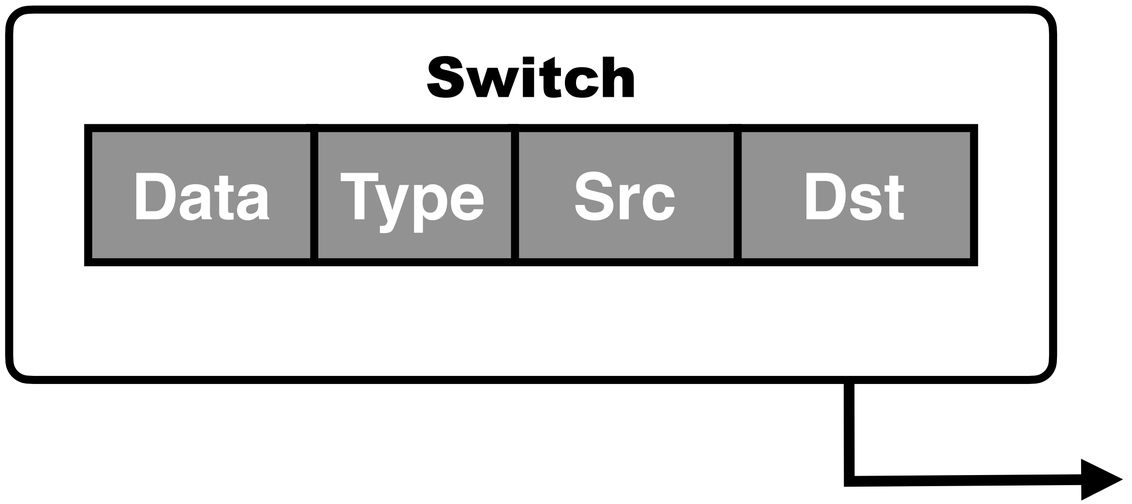
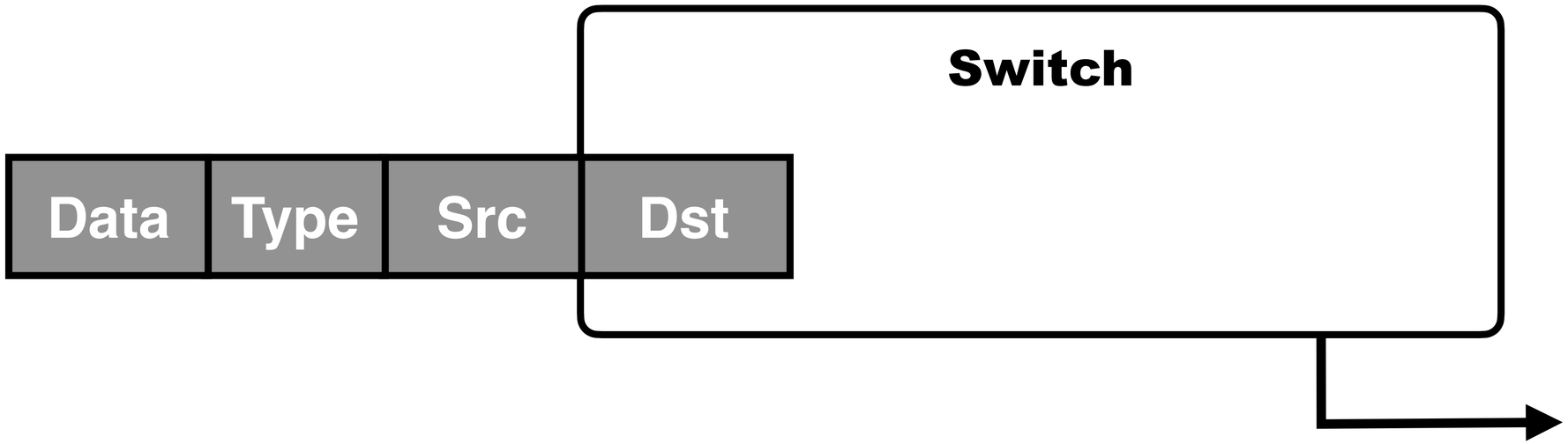


Cut-Through Switching

- The switch can forward the frame before the entire frame is fully received



L2 Switching Enable Scaled Connectivity

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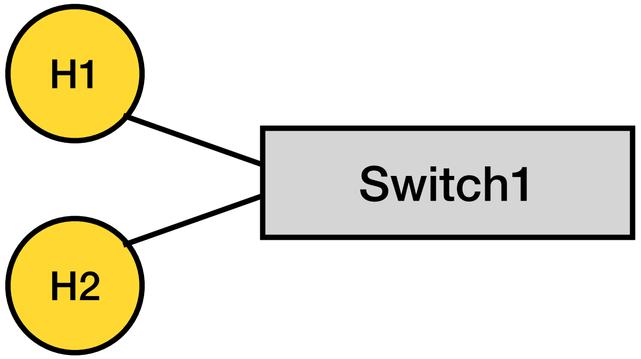

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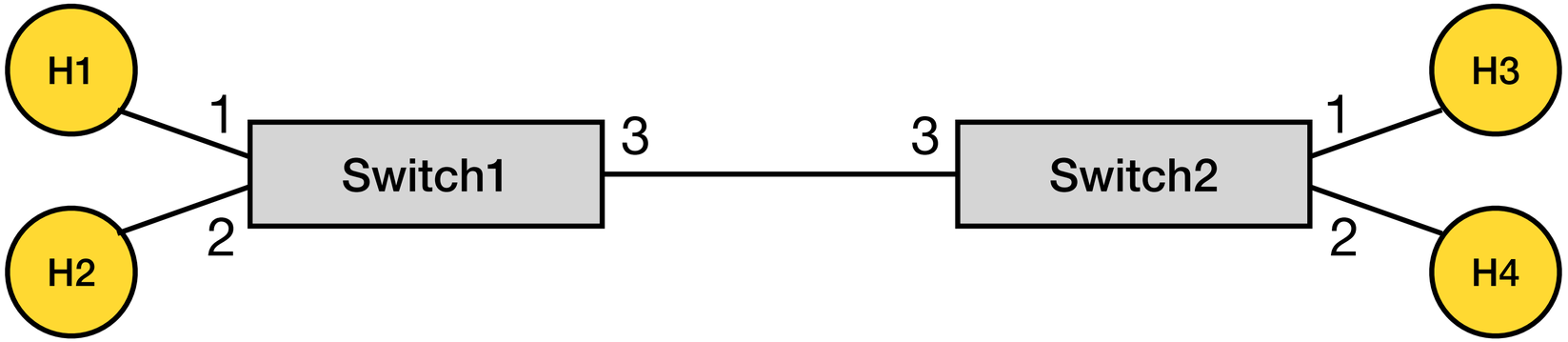

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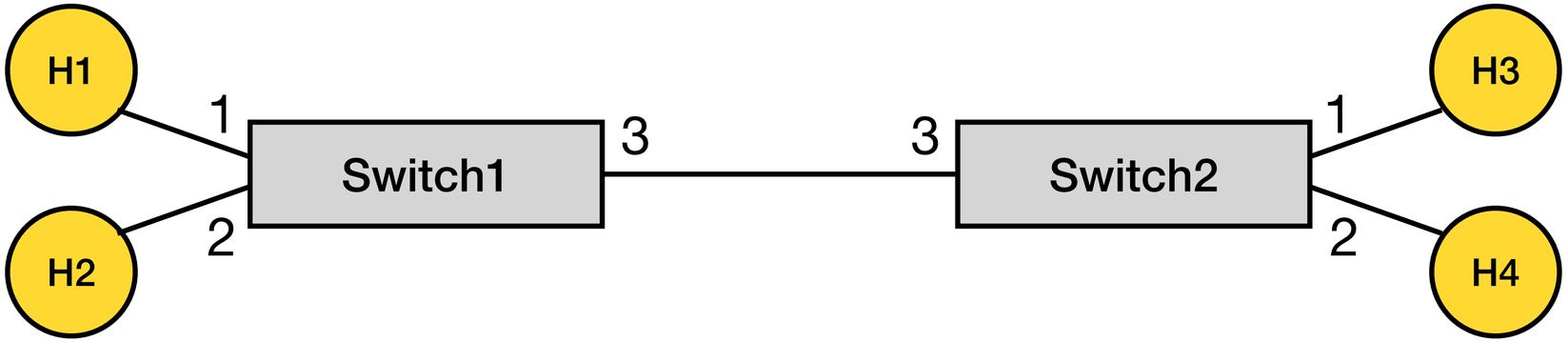

Switch1
Forwarding Table

MAC address	Port	Age (s)
H1 dst addr	1	8
H2 dst addr	2	6
H3 dst addr	3	8
H4 dst addr	3	6

Switch2
Forwarding Table

MAC address	Port	Age (s)
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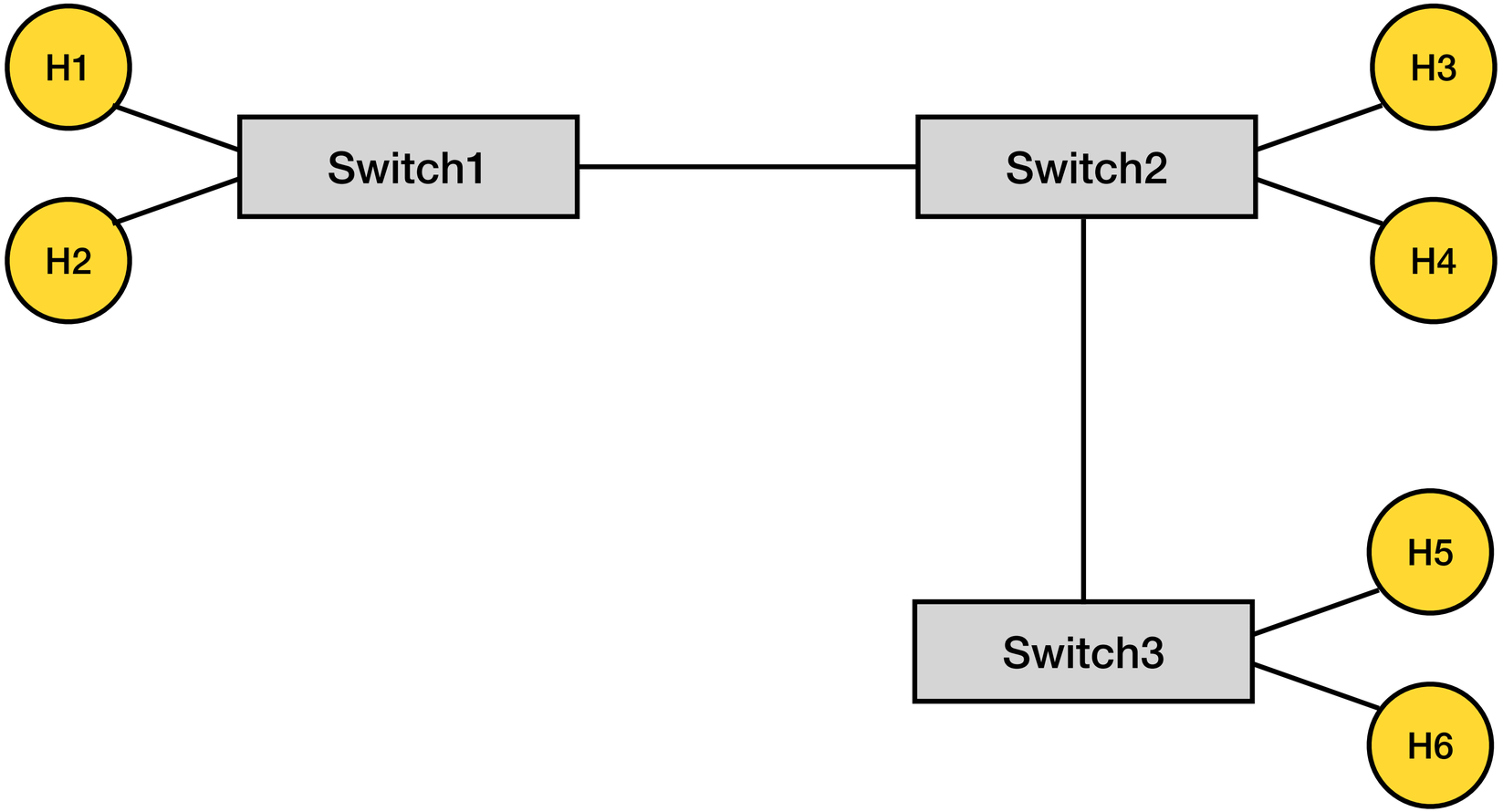

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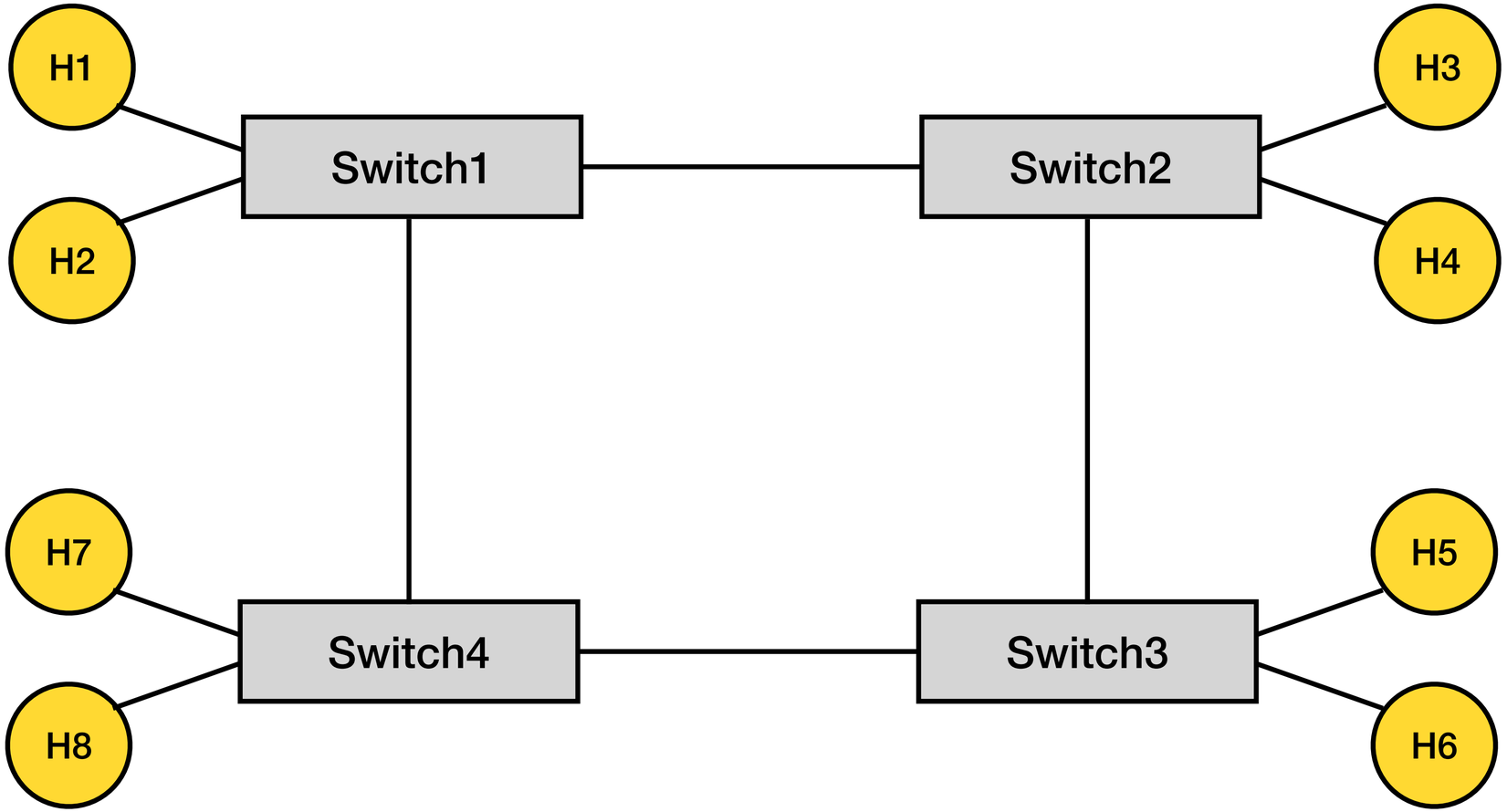

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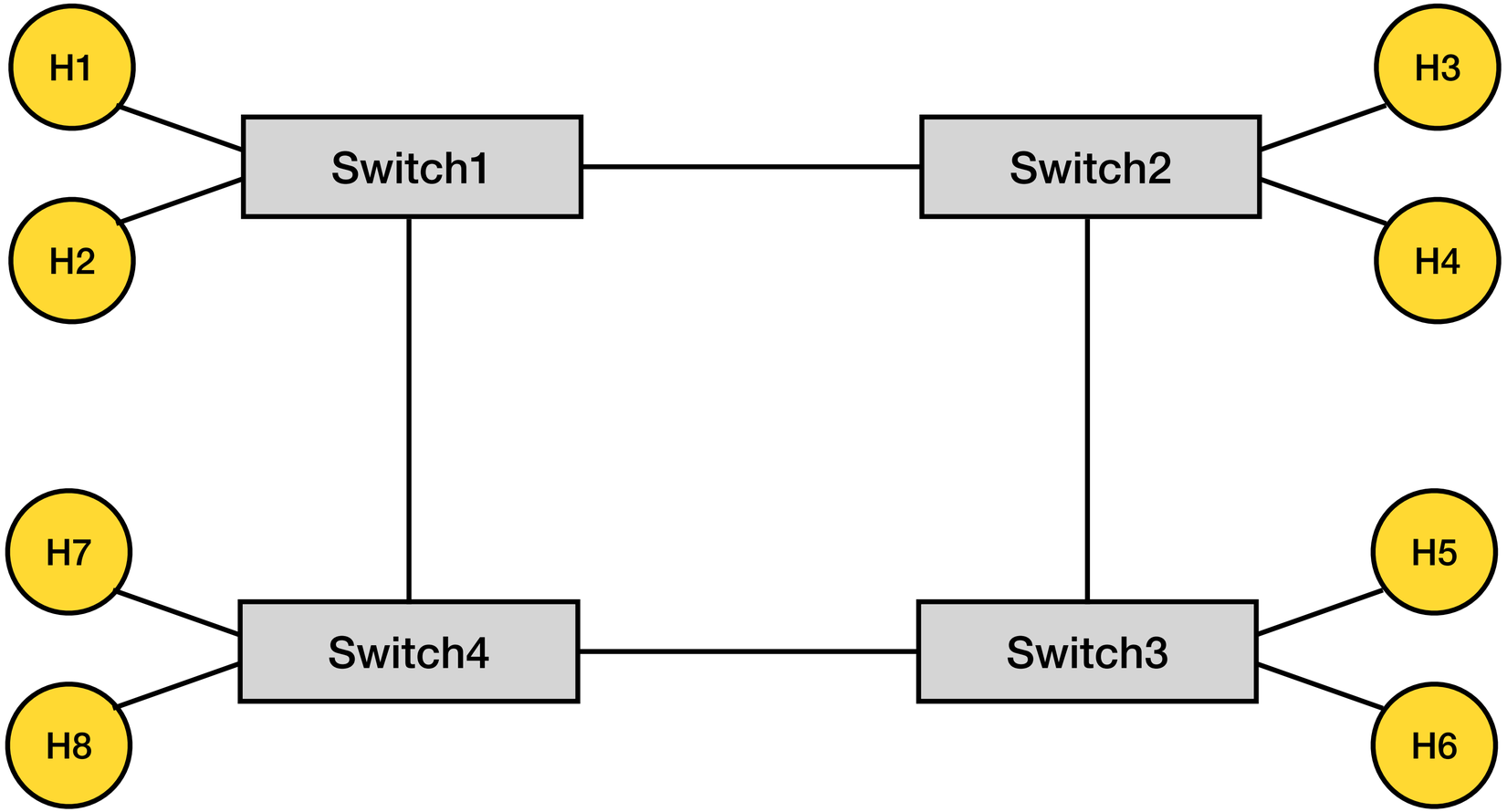
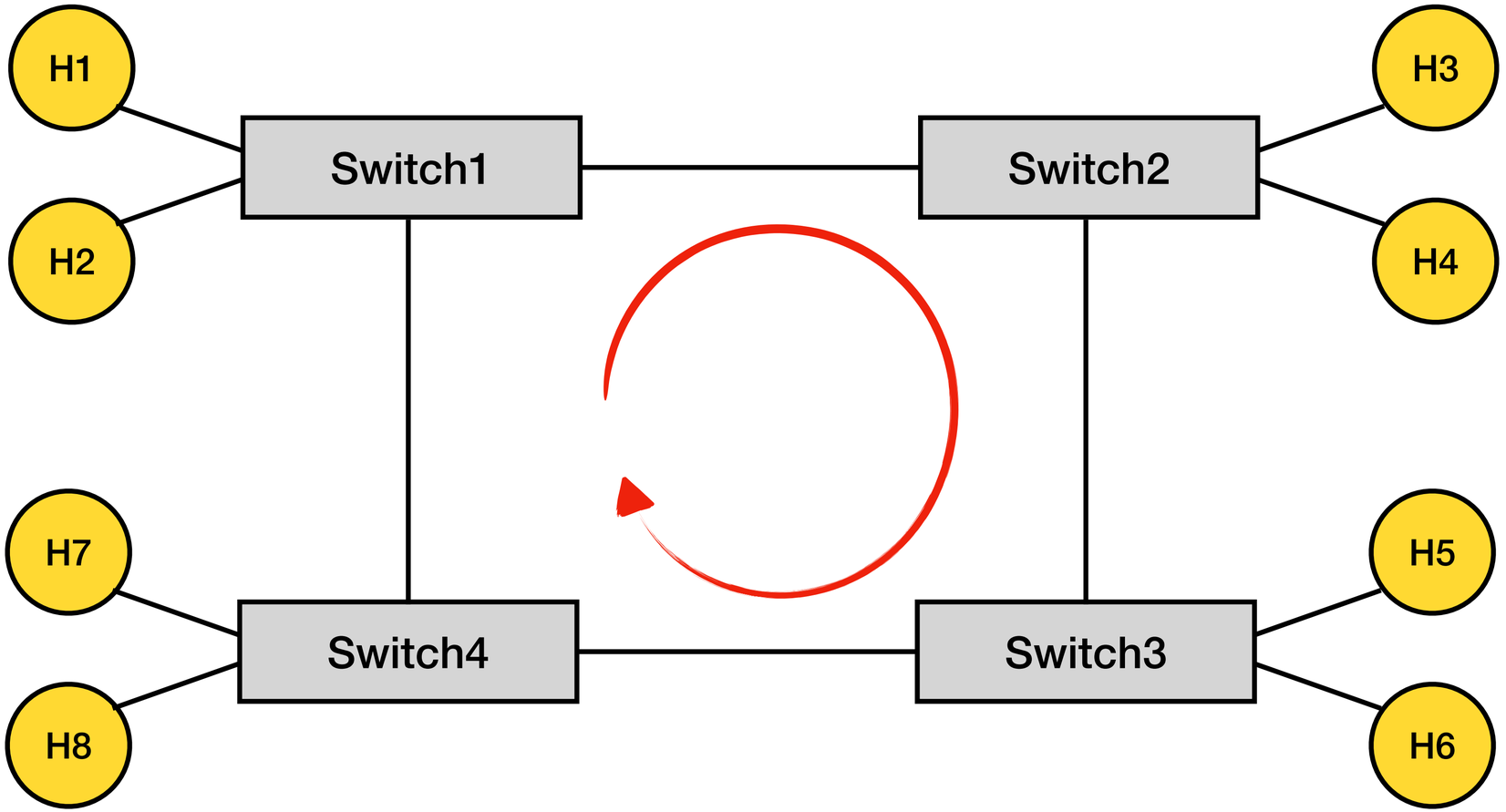


Any problems?

Forwarding Loop

- A topological circle that keeps a frame forwarded
  - Waste switch/router bandwidth!



How can we avoid forwarding loops?

Spanning Tree Protocol (STP)

- A layer two protocol that detects and breaks loops
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  - Standardized as IEEE 802.1D

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A protocol defines the format and the order of messages exchanged between two or more communication entities, as well as the actions taken on the transmission and/or receipt of a message or other event.

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  - What are the protocol messages?
  - What are the actions associated with the message (protocol logic?

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- **Key principle: minimal states**
  - Anytime and anywhere connectivity —> highly scalable systems
  - Not only for STP, but also for other protocols

STP #1: States Maintained at the Switch

- Four states
  - Local switch ID —> Assigned by the network operator

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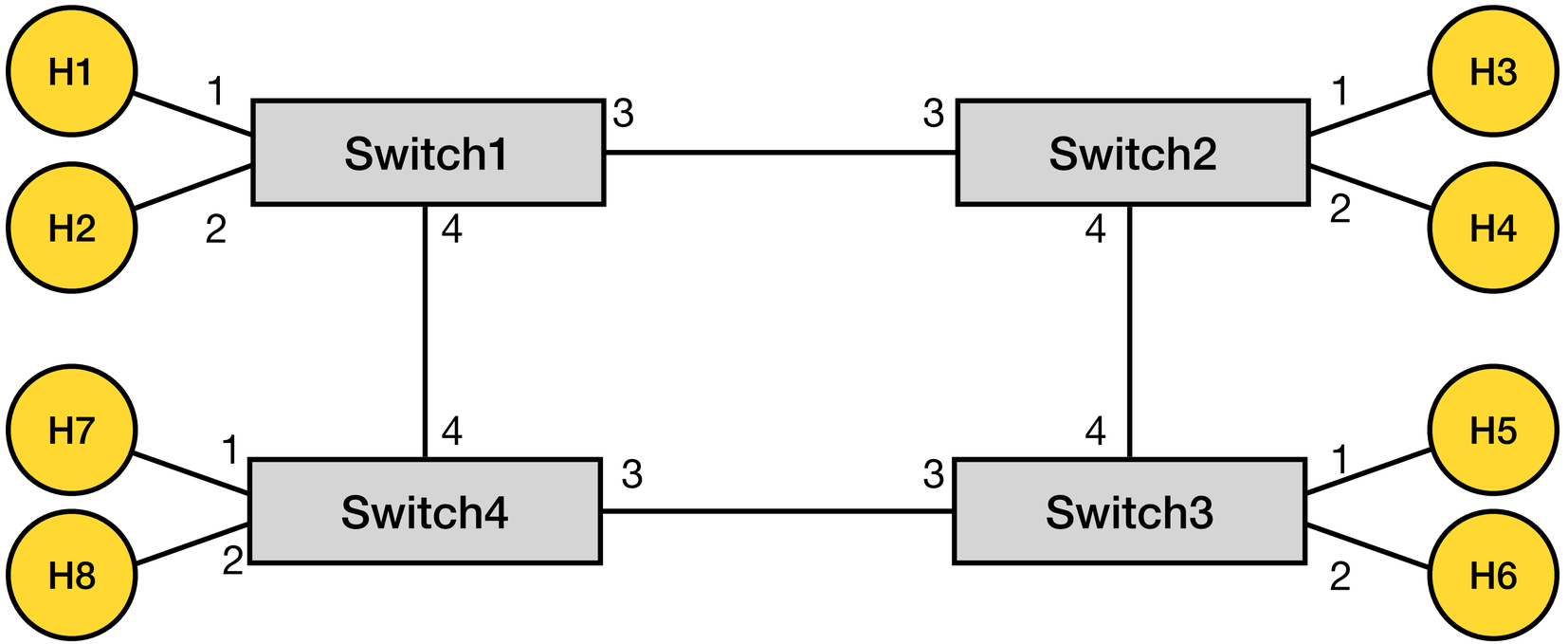
- Four states
  - Local switch ID —> Assigned by the network operator
  - **The switch ID of the root**
  - **The distance and port (i.e., the number of hops) to the root**
  - **Per-port action table**

} STP protocol



STP #1: States Maintained at the Switch

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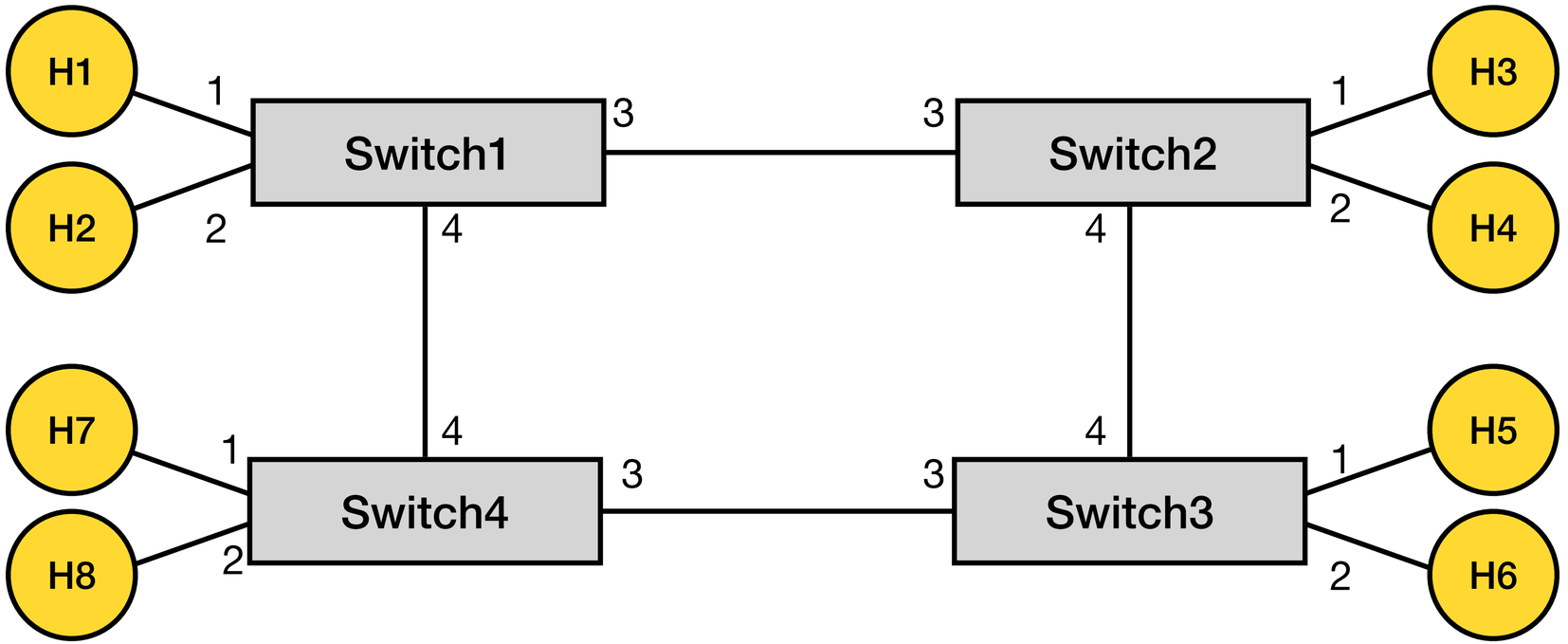
Switch 1							
Switch 2							
Switch 3							
Switch 4							



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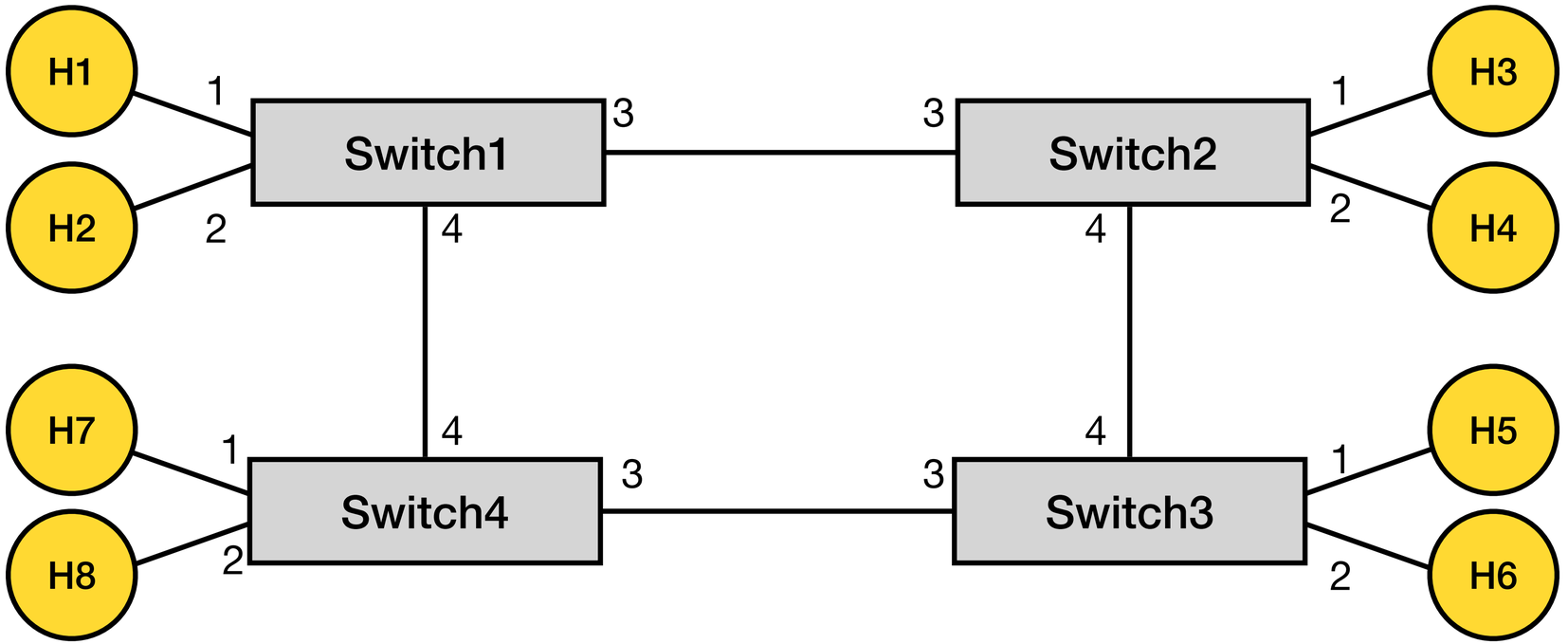

STP #2: Configuration Message

- Three tuples <Y, d, X>
  - Y: the root switch ID in my view
  - d: the distance to the root
  - X: my local switch ID
- The configuration message is issued periodically

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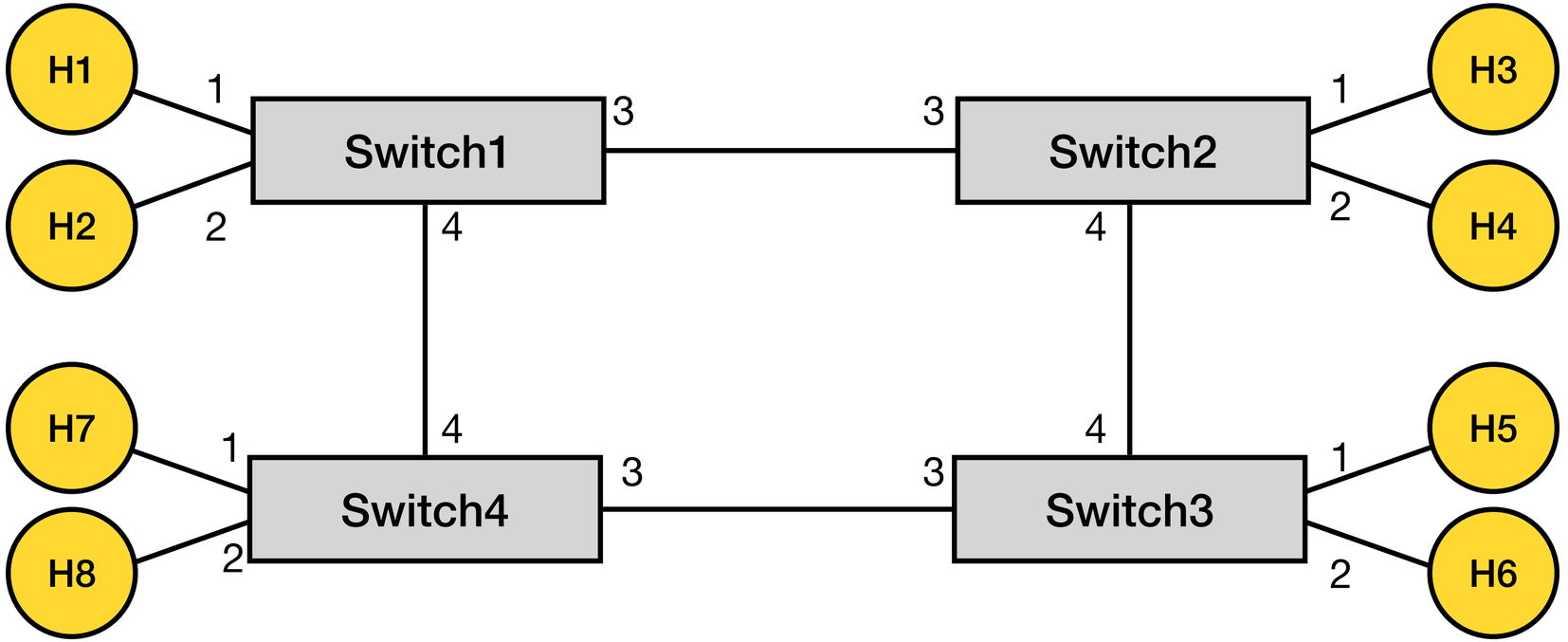

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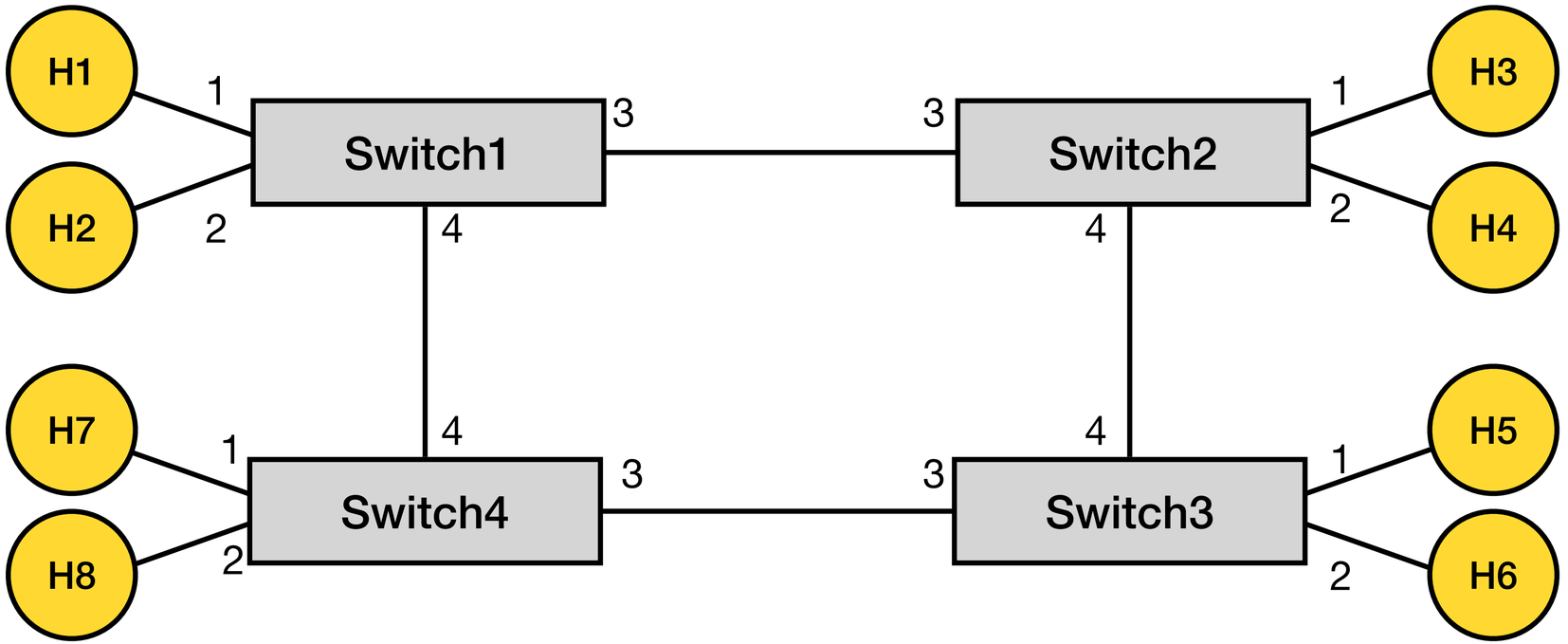

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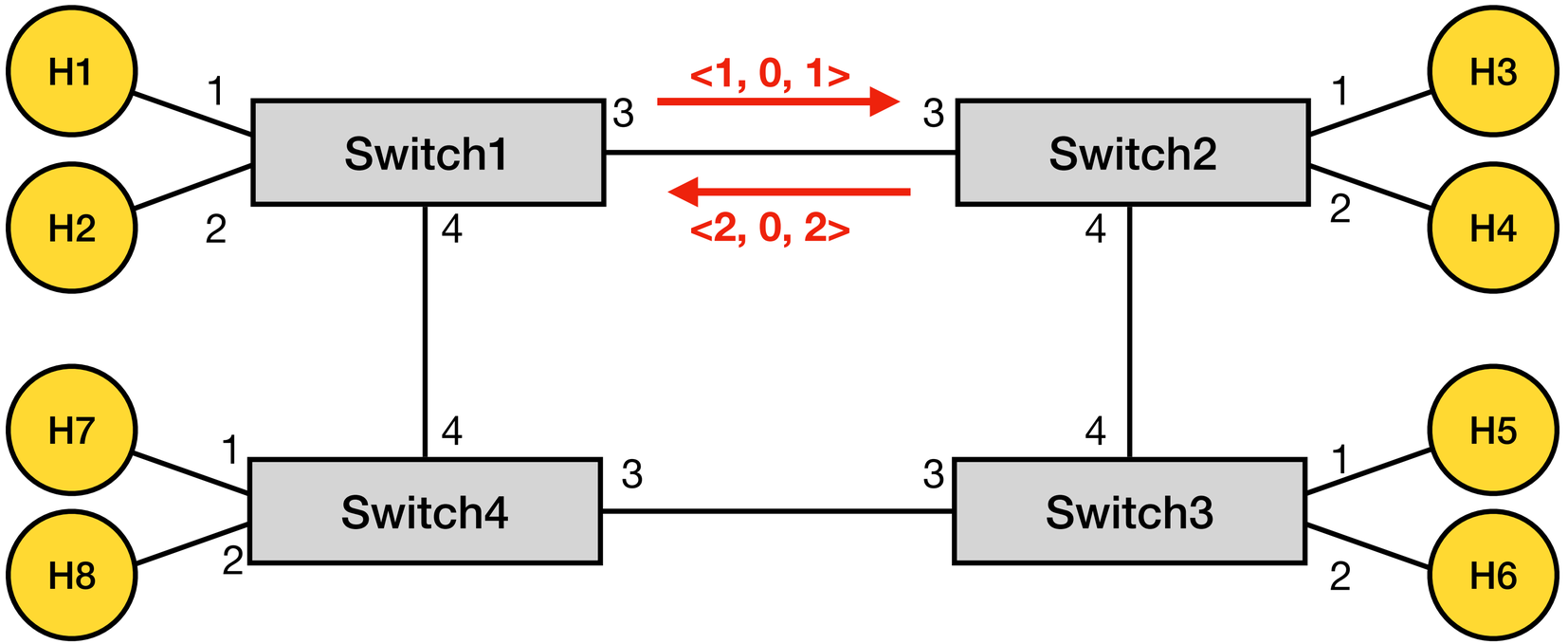
Switch 1	1	1	<0, N/A>				
Switch 2	2	2	<0, N/A>				
Switch 3	3	3	<0, N/A>				
Switch 4	4	4	<0, N/A>				



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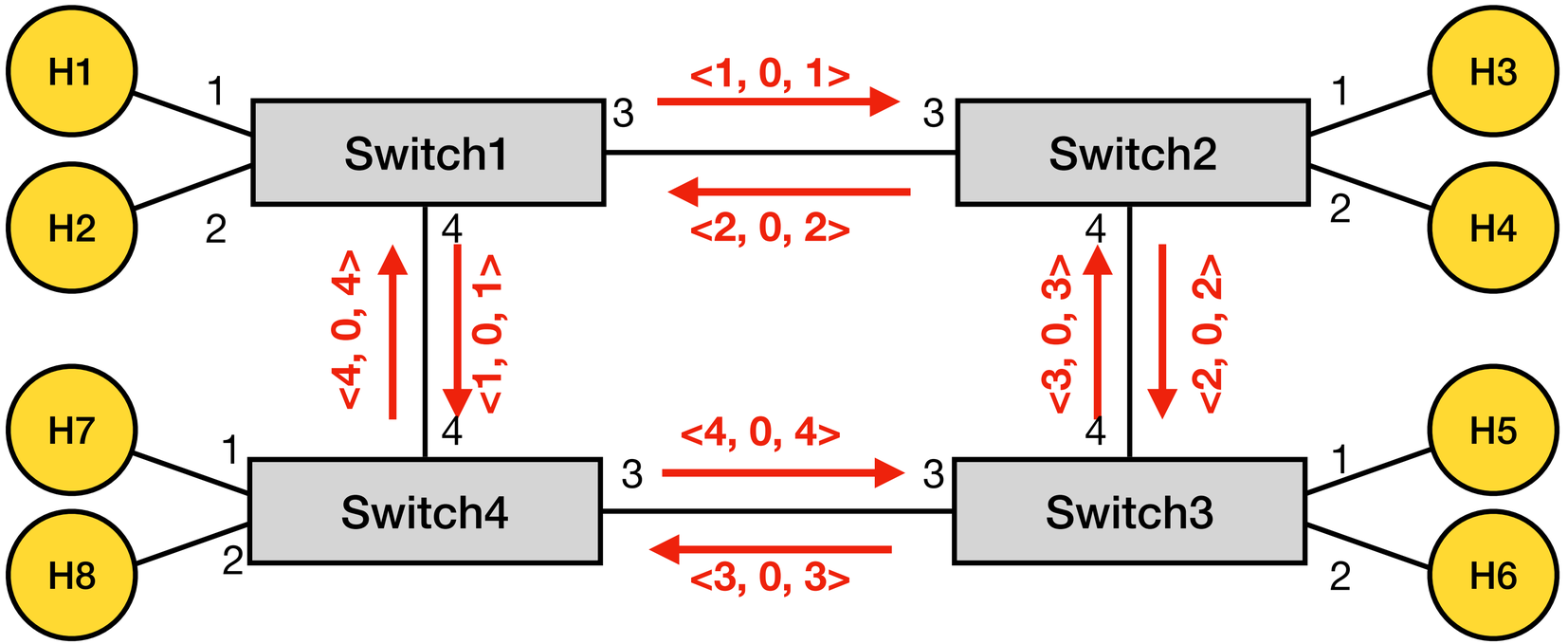
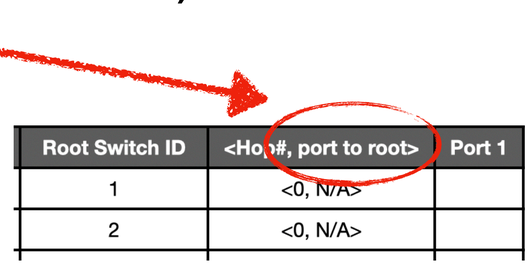


STP #3: Protocol Actions

- Action #1: Root determination
  - If the root switch ID of the configuration message (<Y, d, X>) is **smaller than** the root switch ID of my local states, the switch should accept the new root switch and perform the following four operations:
    - Change my root switch ID to **Y**
    - Update the hop# (d_cur) to **d_cur = d+1**
    - Mark the switch port that receives the configuration message as **"Broadcast_YES (BC_YES)"**
    - Mark the prior saved switch port (if it existed) as **"Broadcast_NO (BC_NO)"**
  - Otherwise, go to Action #2



STP #3: Protocol Actions

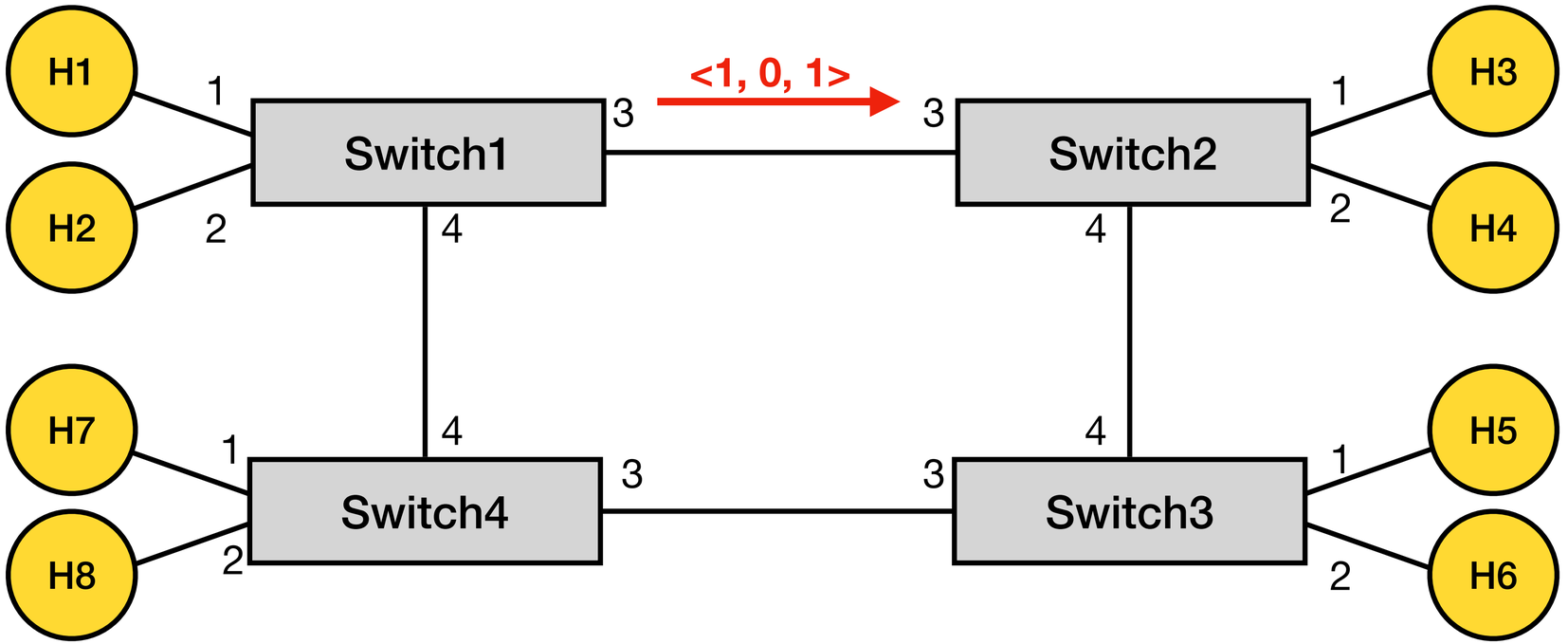
- Action #2: Path determination
  - If the root switch ID of the configuration message (<Y, d, X>) is **the same as** the root switch ID of my local states, the switch should examine the hop# to figure out the shortest path and perform the following operations:
    - If **d+1 < d_cur**, the switch should (a) update the hop# (d_cur) to **d_cur = d+1**; (b) mark the switch port that receives the configuration message as **"Broadcast_YES (BC_YES)"**; (c) mark the prior saved switch port (if it existed) as **"Broadcast_NO (BC_NO)"**;
    - If **d+1 >= d_cur**, the switch should (a) discard the message; (b) mark the switch port that receives the configuration message as **"Broadcast_NO (BC_NO)"**. The root switch skips (b) and marks the port as **"Broadcast_YES (BC_YES)**;
  - Otherwise, go to Action #3

STP #3: Protocol Actions

- Action #3: Discard and block
  - The switch should (a) discard the message: (b) mark the switch port that receives the configuration message as **“Broadcast_NO (BC_NO)”**. If this is the root switch, (b) is skipped and the switch marks the port as **“Broadcast_YES (BC_YES)**;

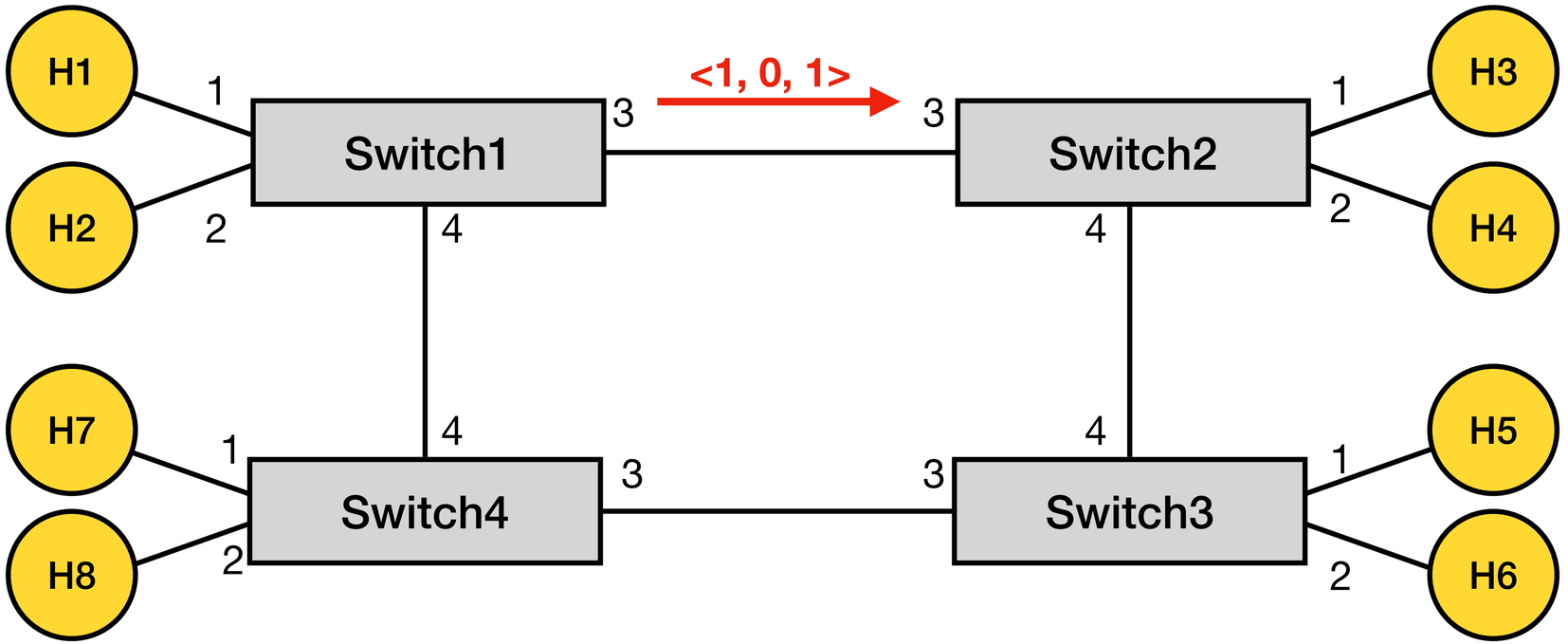
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>				
Switch 2	2	2	<0, N/A>				
Switch 3	3	3	<0, N/A>				
Switch 4	4	4	<0, N/A>				



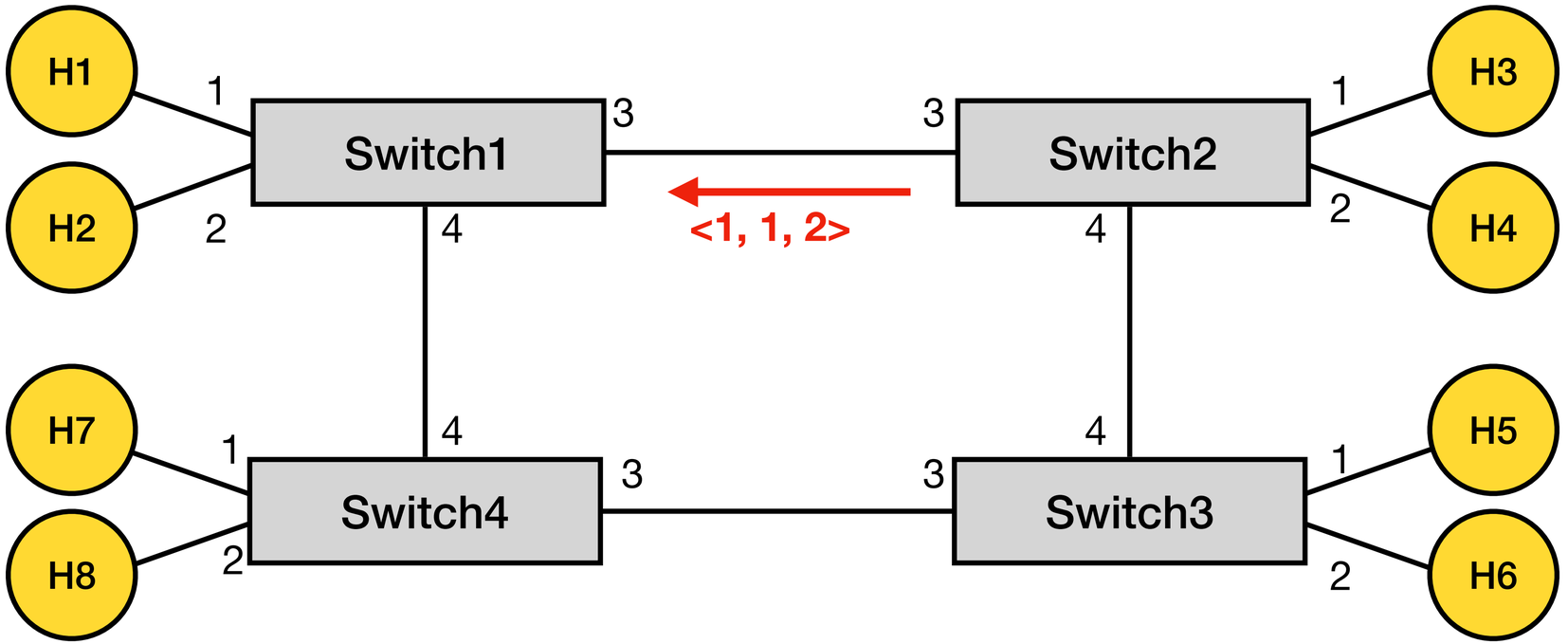
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>				
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	3	<0, N/A>				
Switch 4	4	4	<0, N/A>				



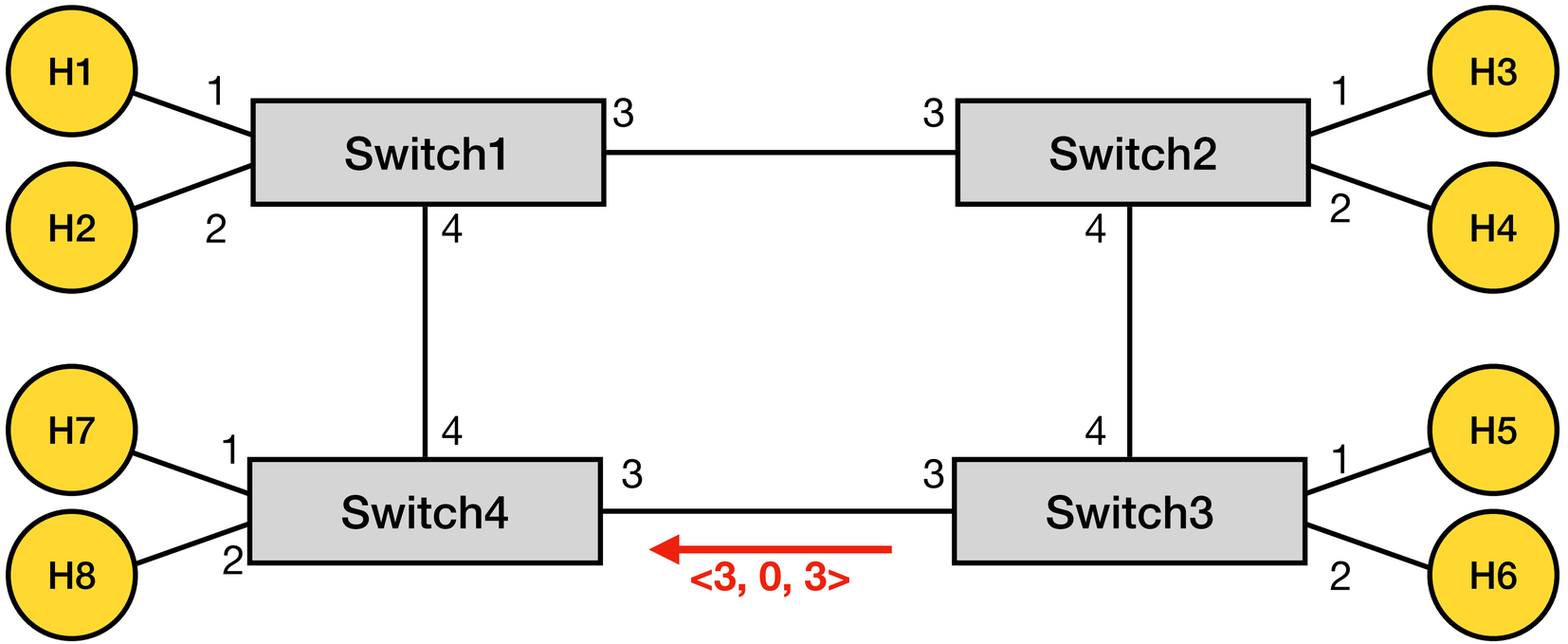
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	3	<0, N/A>				
Switch 4	4	4	<0, N/A>				



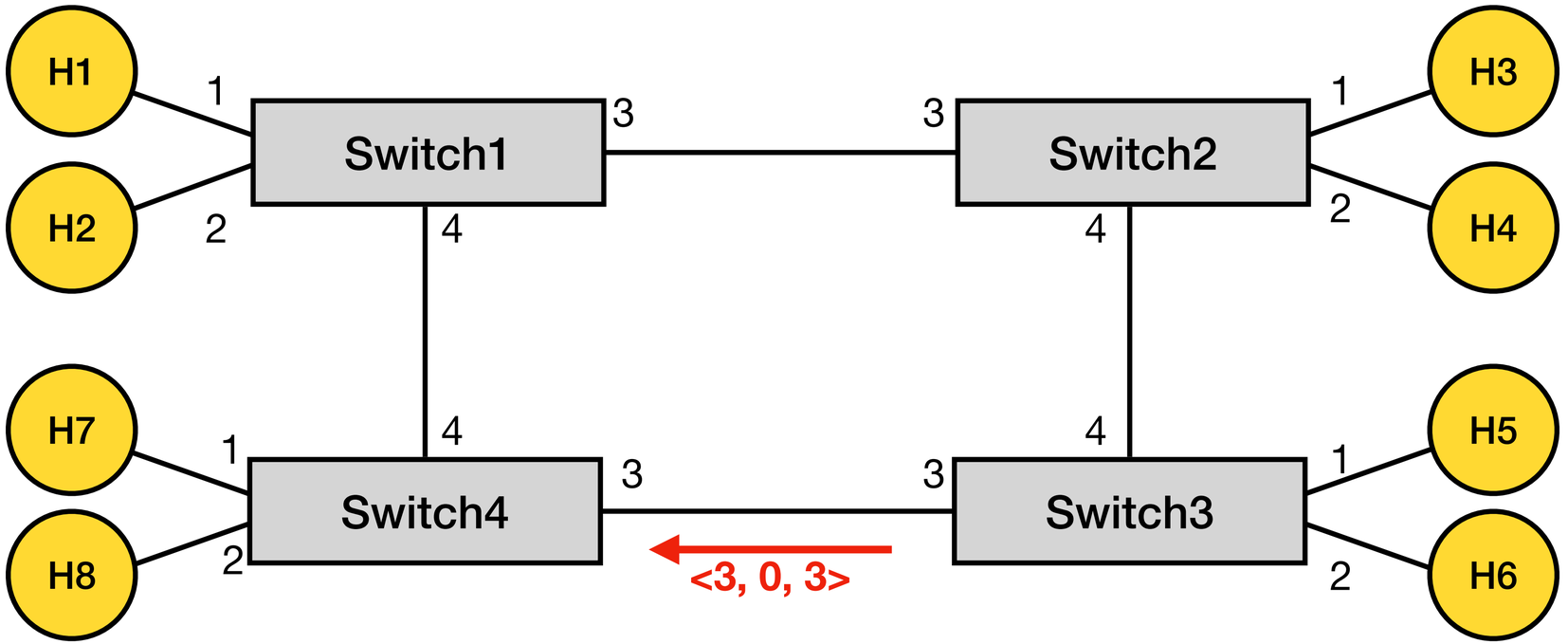
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	3	<0, N/A>				
Switch 4	4	4	<0, N/A>				



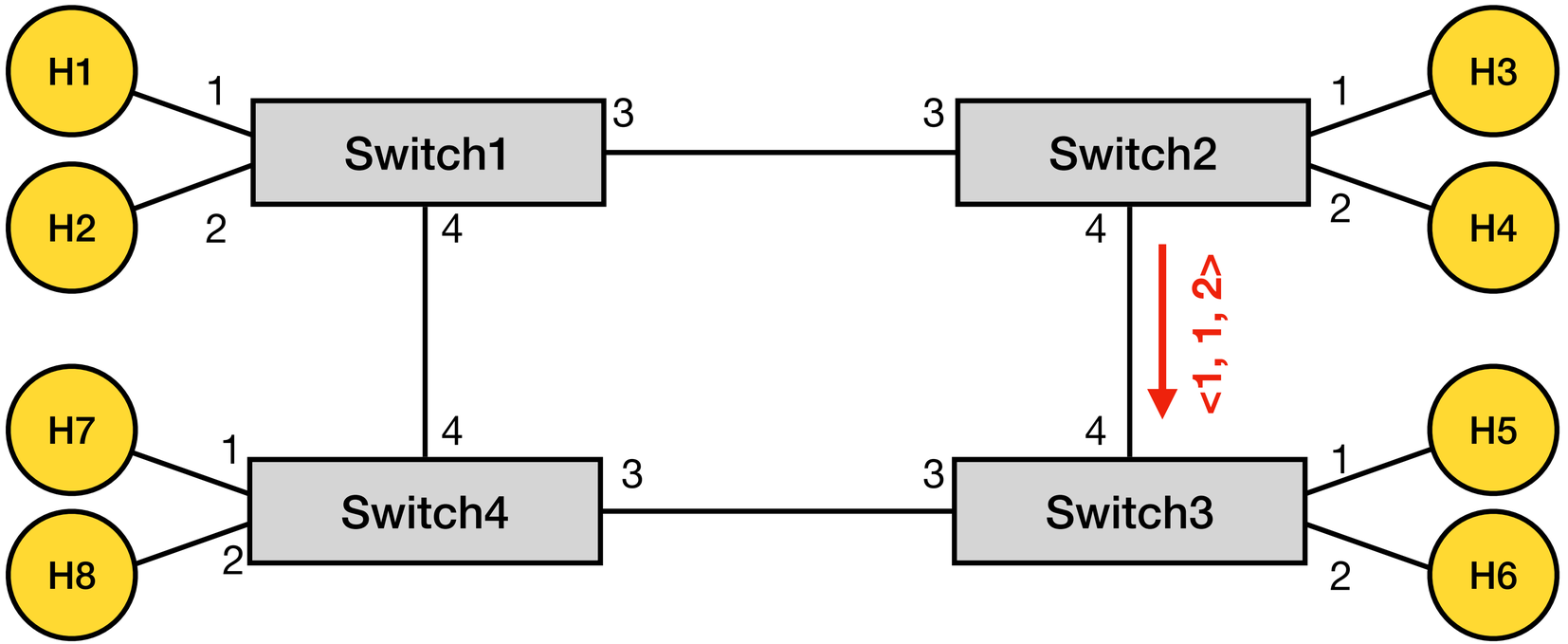
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	3	<0, N/A>				
Switch 4	4	3	<1, 3>			BC_YES	



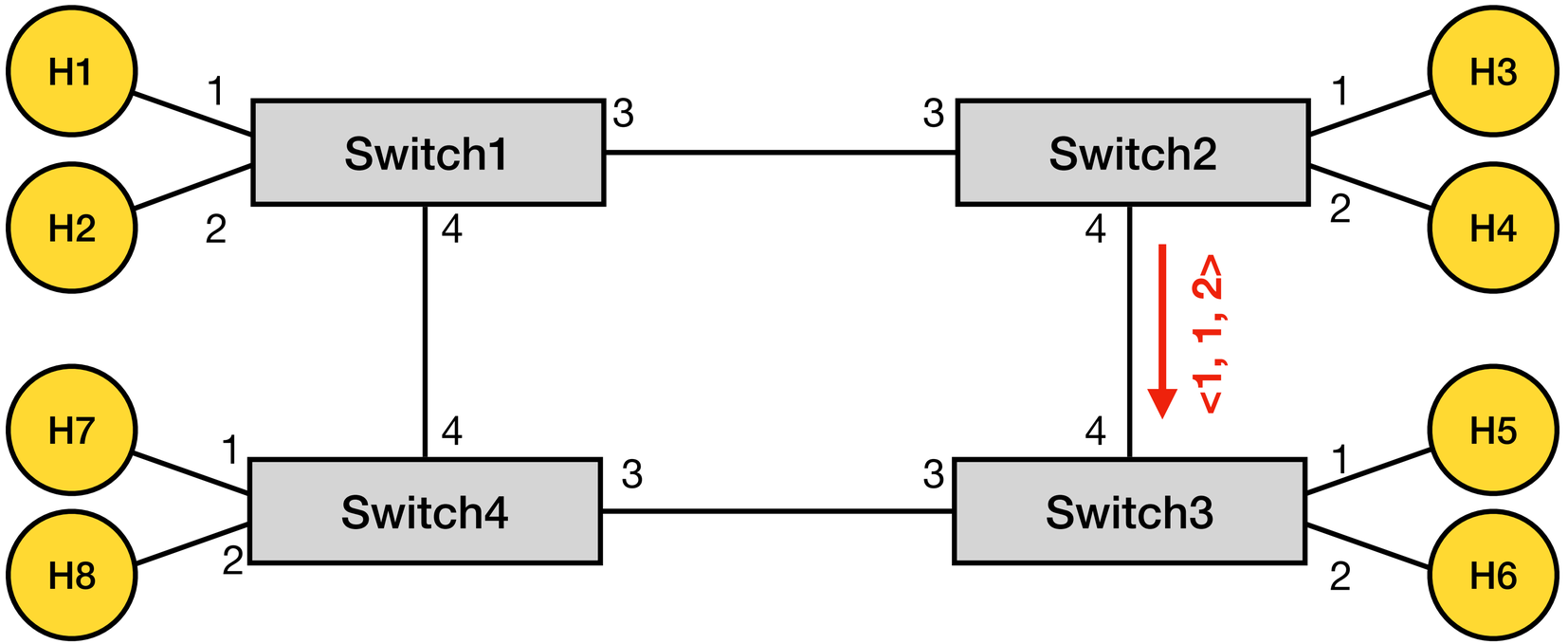
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	3	<0, N/A>				
Switch 4	4	3	<1, 3>			BC_YES	



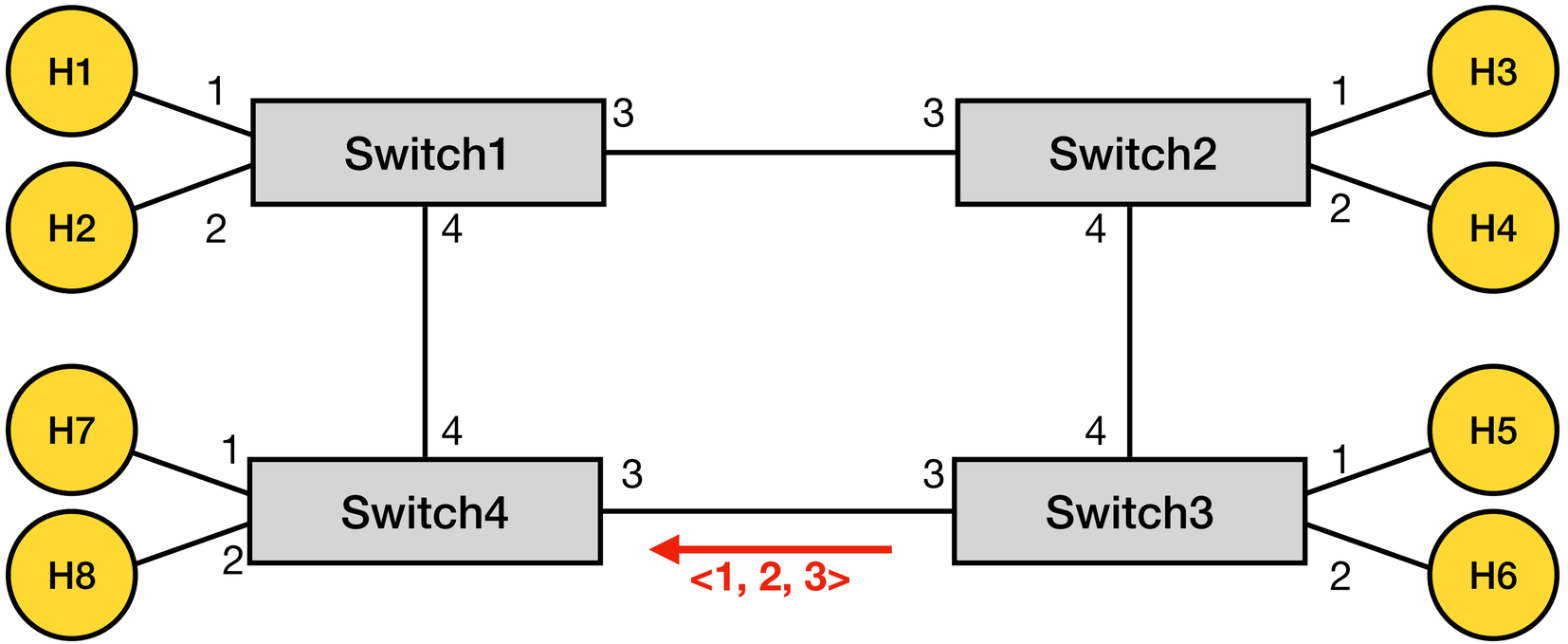
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	1	<2, 4>				BC_YES
Switch 4	4	3	<1, 3>			BC_YES	



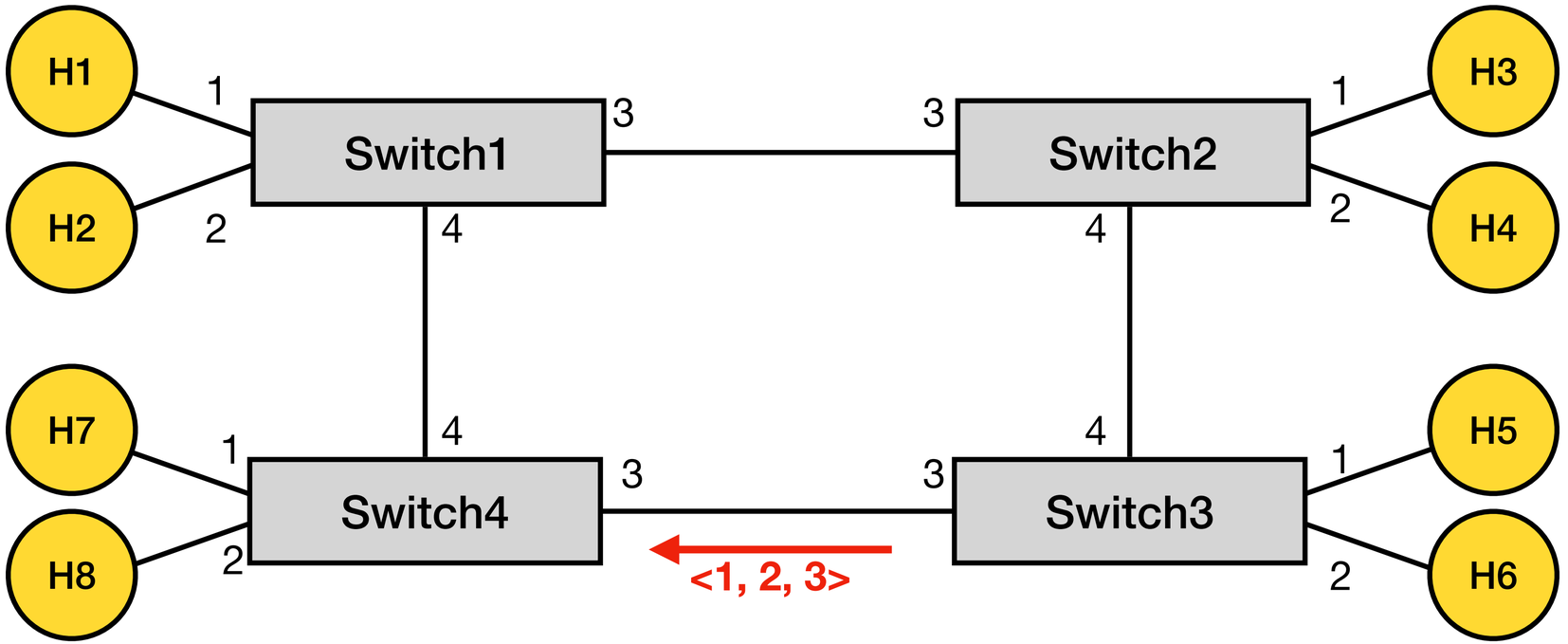
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	1	<2, 4>				BC_YES
Switch 4	4	3	<1, 3>			BC_YES	



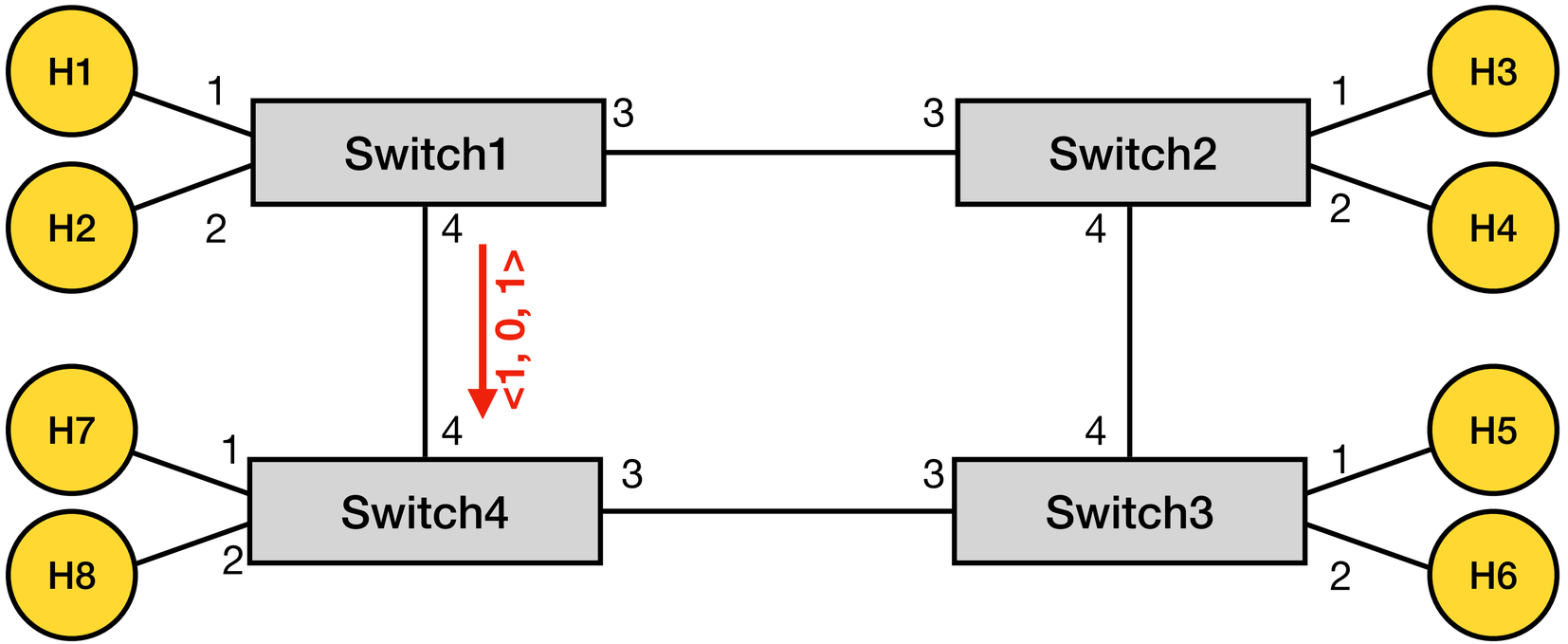
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	1	<2, 4>				BC_YES
Switch 4	4	1	<3, 3>			BC_YES	



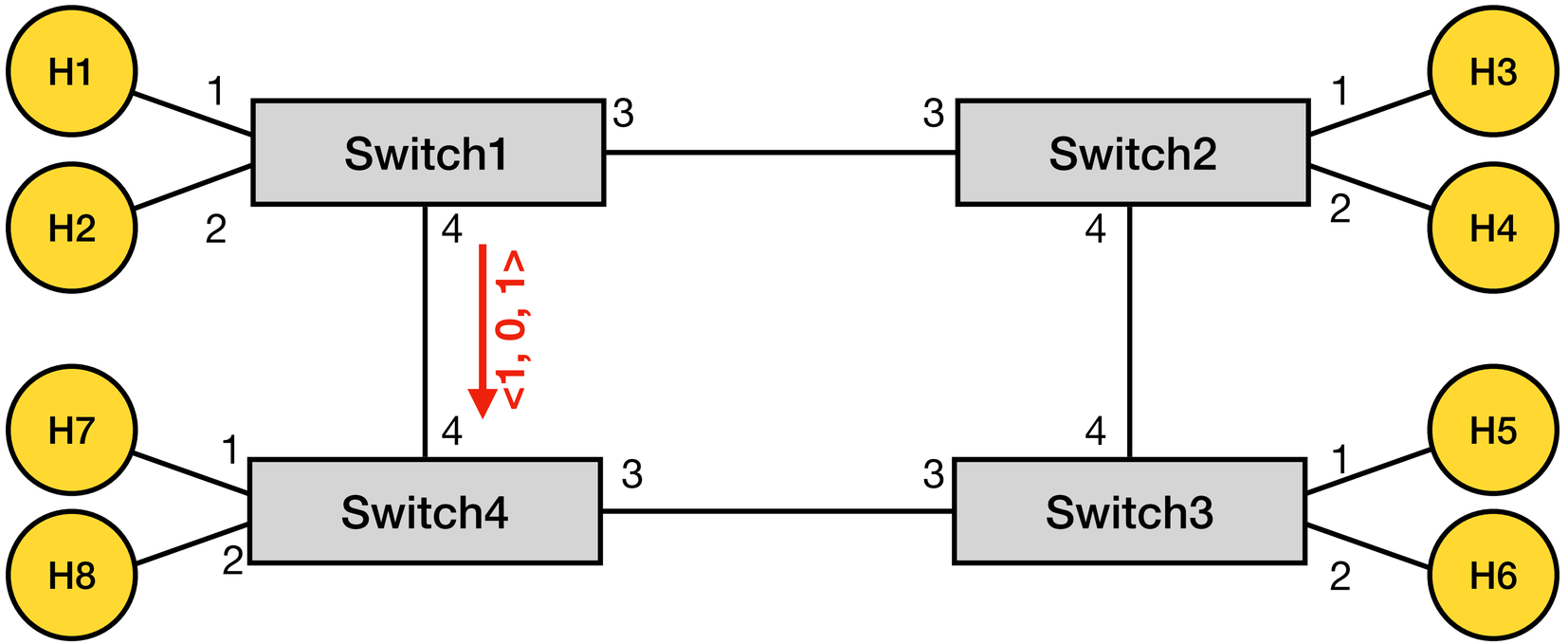
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	1	<2, 4>				BC_YES
Switch 4	4	1	<3, 3>			BC_YES	



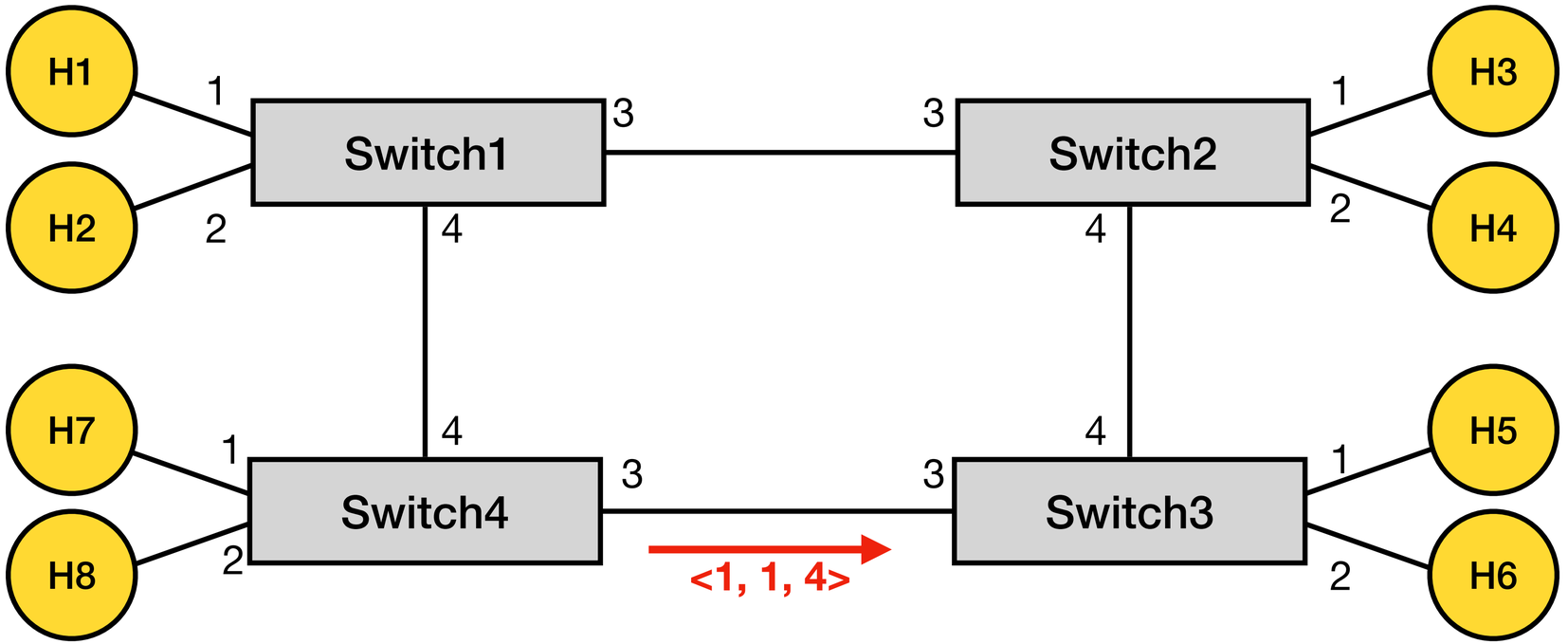
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	1	<2, 4>				BC_YES
Switch 4	4	1	<1, 4>			BC_NO	BC_YES



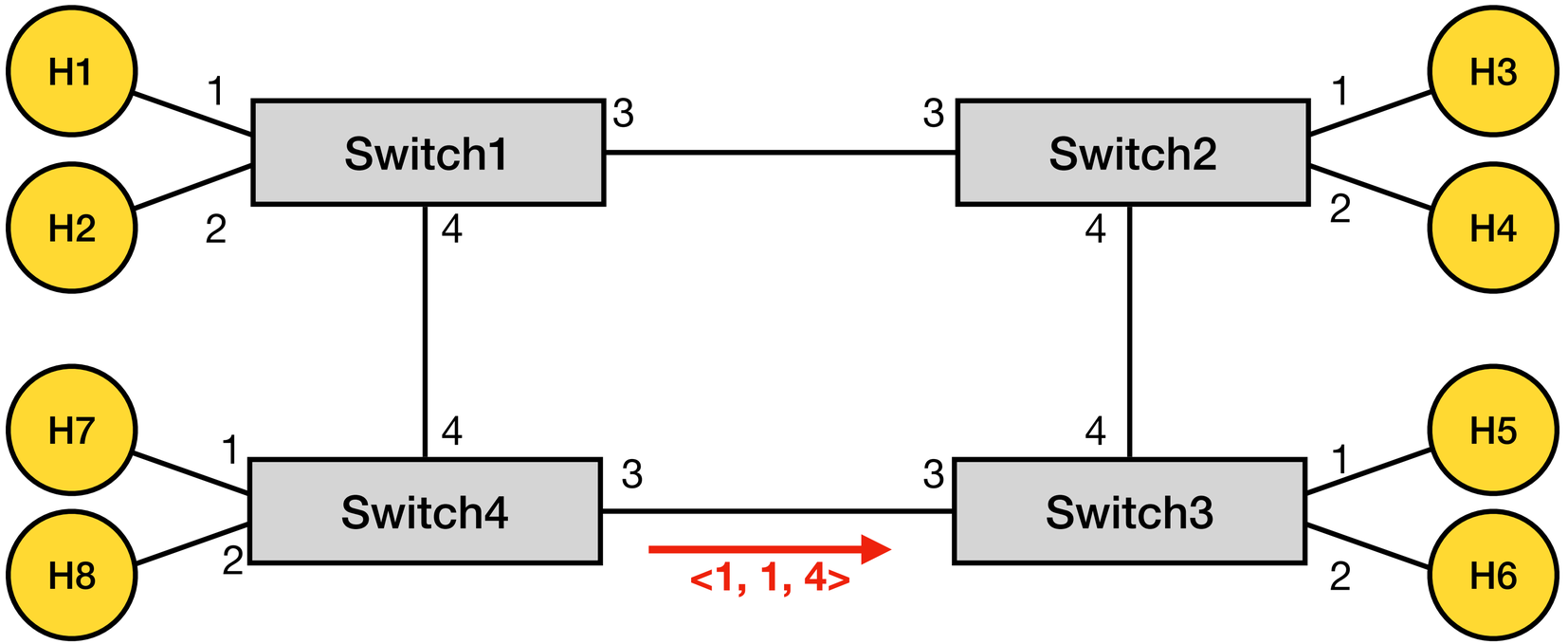
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	1	<2, 4>				BC_YES
Switch 4	4	1	<1, 4>			BC_NO	BC_YES



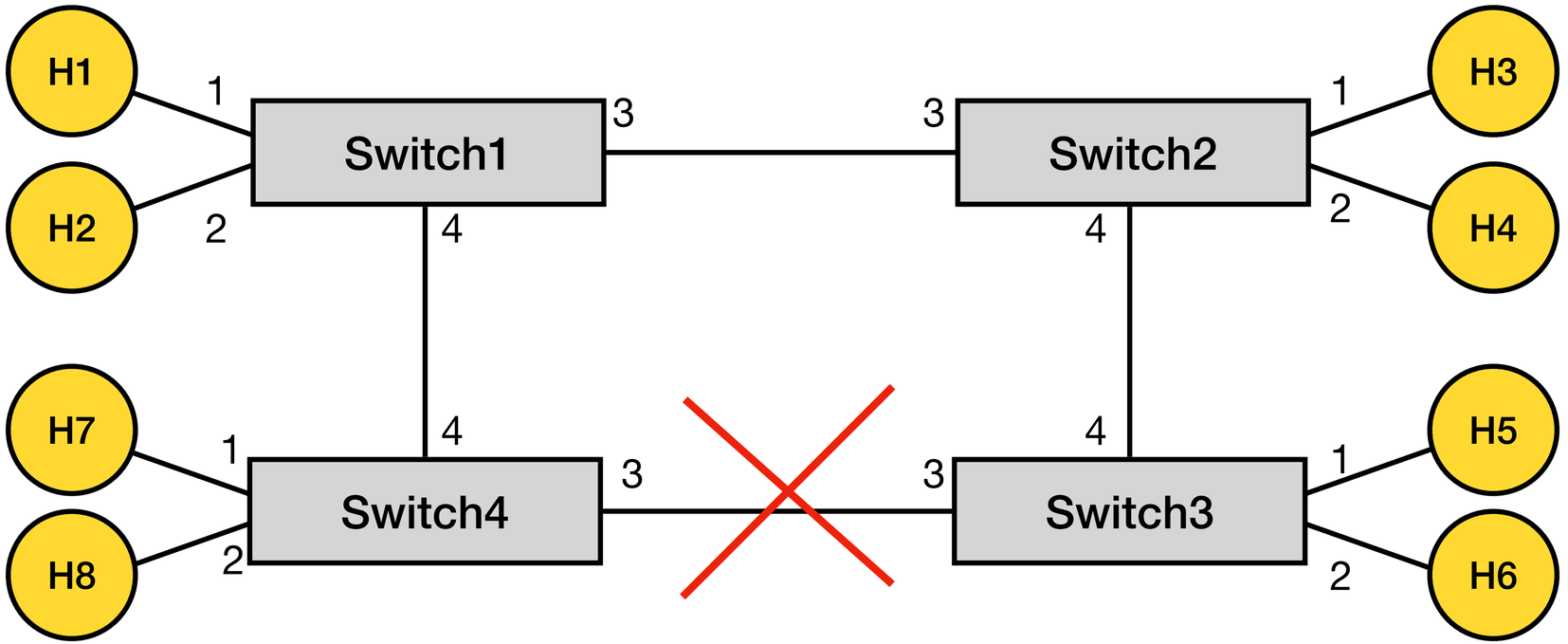
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	1	<2, 4>			BC_NO	BC_YES
Switch 4	4	1	<1, 4>			BC_NO	BC_YES



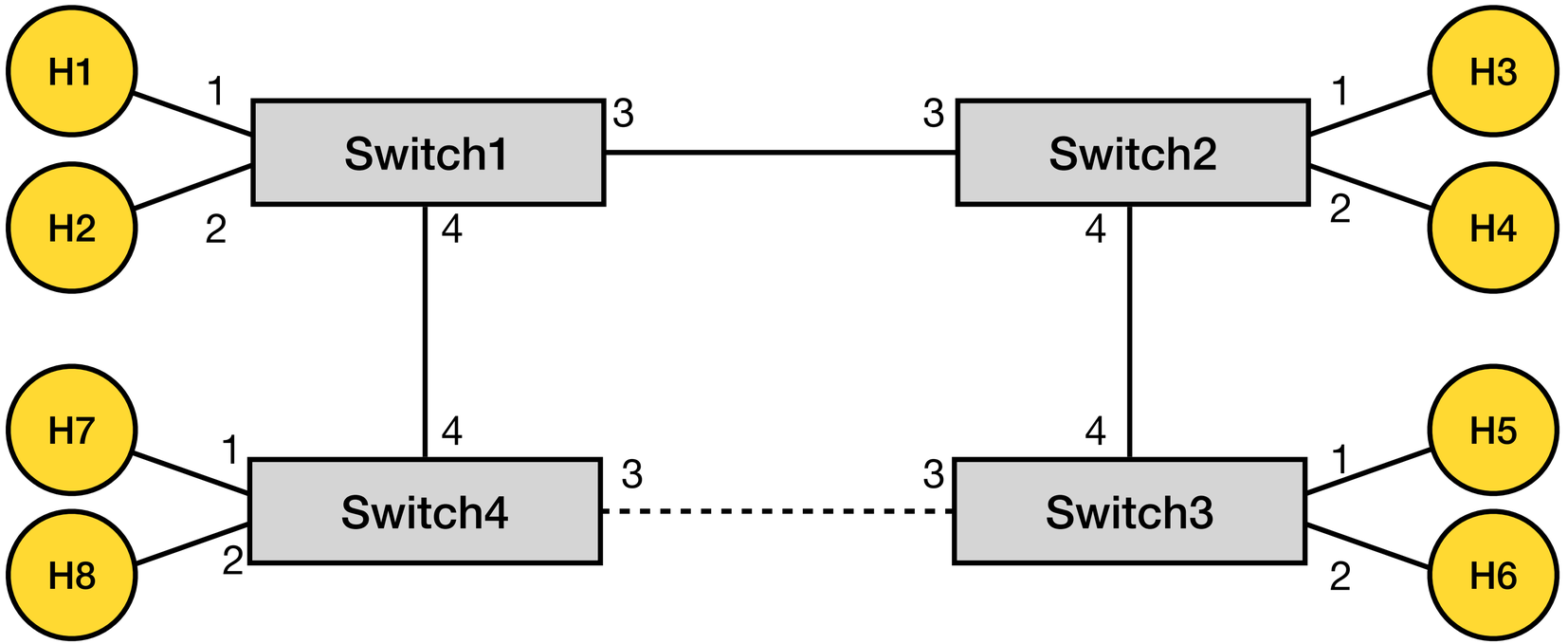
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	
Switch 2	2	1	<1, 3>			BC_YES	
Switch 3	3	1	<2, 4>			BC_NO	BC_YES
Switch 4	4	1	<1, 4>			BC_NO	BC_YES



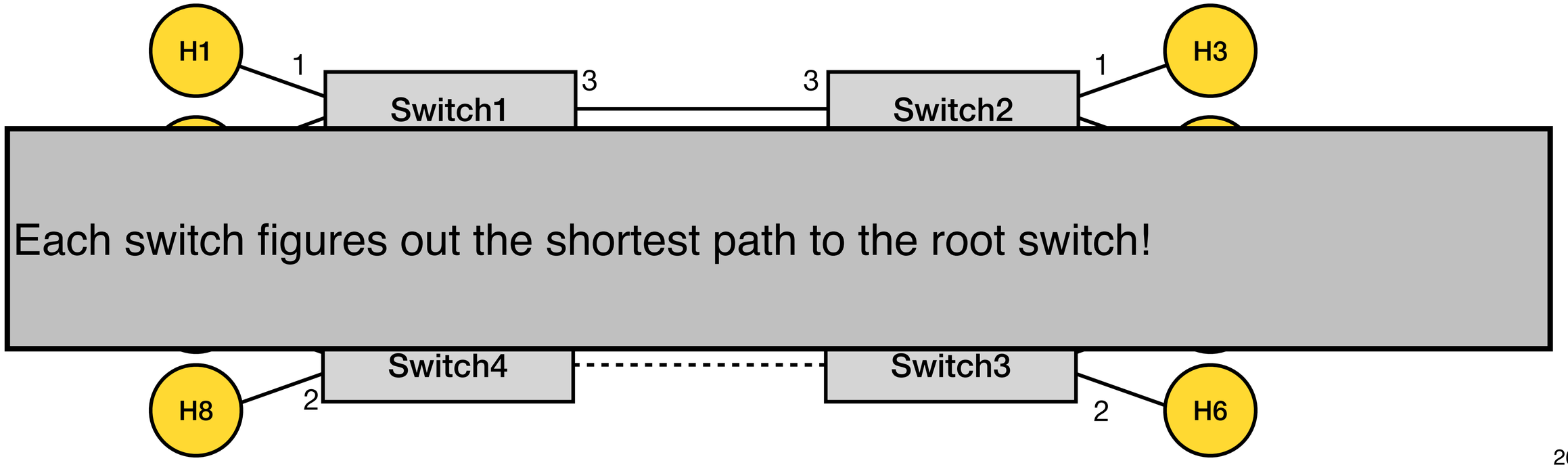
A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	BC_YES
Switch 2	2	1	<1, 3>			BC_YES	BC_YES
Switch 3	3	1	<2, 4>			BC_NO	BC_YES
Switch 4	4	1	<1, 4>			BC_NO	BC_YES



A Running Example

	Local Switch ID	Root Switch ID	<Hop#, port to root>	Port 1	Port 2	Port 3	Port4
Switch 1	1	1	<0, N/A>			BC_YES	BC_YES
Switch 2	2	1	<1, 3>			BC_YES	BC_YES
Switch 3	3	1	<2, 4>			BC_NO	BC_YES
Switch 4	4	1	<1, 4>			BC_NO	BC_YES



STP Discussion

- STP changes a topological graph to a tree
  - Blocking a switching port on broadcasting

- STP runs periodically
  - When a switch recovers from a failure, it restarts from the scratch
  - The states of a switch keep updating when the tree structure changes

Summary

- Today
  - L2 Forwarding
  - L2 mac learning
  - STP

- Next lecture
  - Ethernet
  - Quiz